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REPORTS

FROM

COMMISSIONERS, INSPECTORS,

AND OTHERS;

FIFTY-ONE VOLUMES.

—(*46*)—

SEWAGE DISPOSAL (ROYAL COMMISSION)—*continued*.

Session

29 *January* 1908 —— 21 *December* 1908.

VOL. LVI.

1908.

REPORTS

FROM

COMMISSIONERS, INSPECTORS,

AND OTHERS:

1908.

FIFTY-ONE VOLUMES:—CONTENTS OF THE

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SEWAGE DISPOSAL (ROYAL COMMISSION):

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3.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

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FIFTH REPORT

OF

THE COMMISSIONERS

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TREATING AND DISPOSING OF SEWAGE

(Including any Liquid from any Factory or Manufacturing Process)

MAY BE PROPERLY ADOPTED.

METHODS OF TREATING AND DISPOSING OF SEWAGE.

APPENDIX V.

REPORTS TO THE COMMISSION

By Mr. Baldwin Latham, M.Inst.C.E., and
Mr. R. A. Tatton, M.Inst.C.E.,

UPON THE EFFECTS OF RAINFALL ON THE FLOW OF SEWAGE.

Presented to both Houses of Parliament by Command of His Majesty.

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ROYAL COMMISSION ON SEWAGE DISPOSAL.

FIFTH REPORT.

APPENDIX V.

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Parliament Mansions,
Victoria Street, Westminster, S.W.,
June 29th, 1903.

TO THE ROYAL COMMISSION ON SEWAGE DISPOSAL.

My Lord and Gentlemen,

Fluctuation of flow due to other causes than rainfall.

Influence of water supply.

In order to supply the information required as to the effects of rainfall on sewers it should be observed that there are other things beside rainfall that affect the rate of the fluctuation of the flow in sewers. The quantity and distribution of the water supply has a material effect on the flow in sewers. In districts in which there is a considerable waste of water going on, the flow of the sewers is much more uniform than in districts in which there is no waste, If the water supply of the district is constant there is less fluctuation in the flow in the sewers than in those districts in which the water supply is intermittent and distributed to the district in a few hours per day.

Daily differences in flow.

Rates of flow in eight hour periods.

There is a daily difference in the volume of sewage produced in all towns; usually the largest volume occurs on Mondays, Tuesdays or Saturdays and the least on Sundays. In areas of limited size about one half the sewage flows away in eight hours; the rate of flow in the minimum eight hours of flow is about one half the average rate of flow and the quantity about one third of that flowing in the eight hours of maximum flow; for the remaining eight hours of the day the flow is about at the average rate.

Influence of snow and frost.

Wet day sewage

Manufacturing refuse.

It should also be observed that snow and frost exercise an influence upon the flow in sewers. Snow does not effect the gaugings while it lies on the ground, but in times of thaw, accompanied by rain, it will cause an increase in the flow of the sewers which is spread over a longer period than that due to the time the rain actually falls. In times of frost, more water is used and passed into the sewers, as it is found that people will leave their taps running to prevent their water pipes from freezing, especially at night, and the sewage proper tends to increase, and becomes more uniform in flow, but in time of frost the surface water, which otherwise would pass into the sewers, is locked up, and for a time is prevented from entering the sewers. As a rule on a wet day the volume of sewage proper is less, as less water is used which produces the sewage, so that the fluctuation caused by rain becomes greater on a wet day. The effect of turning manufacturing refuse into the sewers often has the effect of suddenly increasing the flow of sewage at particular times of the day or night.

Size of district affects rate of flow.

The size of the district contributing rainfall and sewage greatly influences the volume flowing in the sewers. If the district is very large and the sewers long, the effect of sewage and rainfall passing into the sewers near the outfall will be that it will flow off long before the distant sewage and rain can arrive at the point of outfall. The effect therefore of the length of the sewer is to defer the flow and spread the discharge over a longer period than the time of actual rainfall. The time of maximum flow in a sewer is usually about 15 hours before the time of mimimum flow, but the time of minimum flow is but nine hours before the time of maximum flow. If the flow was deferred 15 hours the maximum distant sewage and rainfall would arrive when the sewers near the outfall were carrying their minimum quantity; the maximum distant quantity being superimposed on the near minimum quantity, and consequently a uniformity of flow takes place. Just the same at the period when the distant minimum flow takes place, if the flow is deferred nine hours, it would arrive at the point of outfall at the time when the maximum quantity near the outfall is flowing away, which also has the effect of rendering the flow in the sewers uniform.

Leakage. Effect of on fluctuation of flow.

Leakage into a sewer has a most material effect in diminishing the rate of fluctuation of flow in a sewer. Whenever there is subsoil water in the ground, and it is exceptional not to find it, and as the generality of sewers more or less leak, unless specially designed to prevent leakage, as the

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Clay jointed sewer pipes.

materials of which sewers and drains are usually constructed will not stand the constant contraction and expansion to which they are subjected in the course of a year due to seasonable changes of temperature without forming openings for leakage into them. Many of the sewers which were constructed in years gone by in London and other places, were designed to admit subsoil water. Pipe sewers have been largely used made of fireclay or stoneware, and these, in many cases, in past years, were jointed with clay, indeed at one time it was an instruction of the Government Department having cognisance of and having to sanction the expenditure incurred in the construction of sewers, that pipe sewers should be so jointed. Such clay jointed pipe sewers always leak, and direct openings are formed by the settlement of the spigot within the socket of the pipe. Many of the pipe sewers of Croydon were, and are, still jointed with clay, and the Croydon Authorities, to the writer's knowledge, although they were advised that it was wrong so to joint sewers, continued this mode of construction, as they would not incur the slight additional expense of jointing them in cement and tarred gasket, a method which the writer introduced in order to make better and more watertight sewers than had hitherto been constructed.

Leakage diminishes rate of fluctuation of flow.

In order to measure the true fluctuation caused by rain in sewers it is necessary to know whether or not the sewers do contain subsoil water, and to what extent, which by adding to the daily flow in the sewers thereby diminishes the rate of fluctuation of the flow in the sewers.

Advantages and disadvantages of leakage of sewers.

It is no doubt a sanitary advantage to have the subsoil water removed from the site of a town. A leaky sewer is a sanitary sewer so long as the flow is always inwards, but a leaky sewer that will pollute the subsoil or subsoil water is dangerous. Leakage is greatest in sewers as a rule in the late winter and early spring of the year, and least in the autumn or early winter

Constant variation of flow in sewers.

As there is a constant variation going on in the flow through sewers, due to the fluctuating character of the flow in the sewers, it is difficult to say what the precise quantity due to rainfall in a sewer will be at any particular hour. The writer has known sewers in small districts in which the ordinary variation of flow in dry weather between the hour of maximum flow and the hour of minimum flow has varied as 8 to 1, and in all places there is a constant fluctuation in the rate of the flow in the sewers.

Variation of flow in small districts.

Effect of rainfall on sewers.

It should also be noted that a certain amount of rain must fall in order to saturate the surface of the ground before any rain can flow off, and therefore some small rains in dry weather do not affect the sewers at all. The sewers are always affected for a less number of days in the year than those on which rain falls. All the rain that falls does not flow off and this is one of the important points to be determined as to the volume of sewage and rainfall which ultimately has to be treated at the point of outfall. From experiments which the writer has made, the greatest amount of rain which flows off from a slated roof in the course of a year does not exceed 80 per cent. of the actual rainfall. In other cases the quantity falling upon other surfaces, such as streets, roads, gardens, and yards, is very much less in proportion to that falling upon a slated roof. It has been observed that only a portion of the rain that falls passes into the sewers, and the rest is evaporated, absorbed, or otherwise lost. The consequence is that the provision to be made for rainfall in sewers is always considerably less than the actual rainfall.

Eighty per cent. of rainfall flows off a slate roof.

Only a portion of rainfall passes to sewer.

Rate of rainfall, Croydon, 1879-1882.

In the case of the Croydon sewers, in four years 1879 to 1882, the actual average rate at which rain fell was 3·93 cubic feet per acre per minute. Now, if only two-thirds of this quantity flowed off, the provision for rainfall would be reduced to 2·62 cubic feet per acre per minute, or if only one-third of the rain flowed off, the provision for rainfall would be reduced to 1·31 cubic feet per acre per minute. It will hereafter be seen that the actual quantity of rain flowing off by the sewers of Croydon in seven years 1880 to 1886 was but 38·92 per cent. of the actual rainfall.

Proportion of rainfall flowing off at Croydon in seven years.

Flow of rainfall, variable quantity.

The rate at which rain flows off the ground, is an extremely variable quantity, as it varies with the geological character of the district, the slope of its surface, and with the size of the district draining to the sewers, and also as to whether or not there are any special provisions in the town for intercepting the rainfall from the sewers.

Proportion of rainfall flowing off at Rhyl.

Tables Nos. 1 & 2

In order to determine the proportion of rain which flows off the surface by the sewers, the writer has had experiments made at different times and at various places, as for example:—In the town of Rhyl, North Wales, for two entire years, 1900 and 1901, the results of which are given in Tables Nos. 1 and 2. The whole of the sewage and rainfall of Rhyl is pumped and the volume is accurately known. The area from which the rainfall is contributed to the sewers is 152 acres, and the results given in these Tables shew that the rainfall flowing off was, in the year 1900 equal to 34·39 per cent. of the dry weather flow of the sewage, and 30·6 per cent. of the dry weather flow of the sewage in the year 1901, or an average of 32·5 per cent. of the dry weather flow in the two years.

In this case the increase due to rainfall is calculated on the quantity of sewage pumped on the dry days, and contains a certain amount of leakage, for when compared with the volume of water supply furnished to the district, the percentage of rain flowing off in the year 1900, was 46·37 per cent., and in 1901, 38·34 per cent., or an average over the two years of 42·35 per cent. including the water entering from the subsoil. The volume of dry weather sewage in 1900 was 40·69 gallons per head per day, while the water supply was 30·18 gallons per head per day. The volume of dry weather sewage in the year 1901 was 39·27 gallons per head per day, while the water supply was 31·39 gallons per head per day, calculated on a population of 8,300 in 1900, and 8,500 in 1901.* The rainfall for the year 1900 was 26·52 inches, of which 12·296 inches in depth flowed off by the sewers exclusive of leakage, which was equal to 46·37 per cent. of the actual rainfall in the year.

In 1901 the rainfall was 20·46 inches in depth, and 10·827 inches flowed off by the sewers exclusive of leakage which was equal to 52·92 per cent. of the actual rainfall in the year.

Proportion of rainfall flowing off at Deal.

Table No. 3.

In the town of Deal, all the sewage of which is pumped, and which at the time of observation had an area of 100 acres draining to the sewers, Table No. 3 gives the results of 18 months pumping, ending February, 1903. The percentage of rain flowing off, compared with the water supply, was 22·87 per cent., and 20·35 per cent of the dry weather flow of the sewers; the actual rain falling at the sewage pumping station was 33·525 inches, and the rain flowing off 13·71 inches, or 40·89 per cent. of the rain falling flowed off by the sewers.

Croydon. Proportion of rainfall flowing off.

In the case of Croydon, gaugings extending over seven years and hereafter dealt with, the percentage of rain flowing off was found over this long period to be 38·92, varying from 43·36 per cent. in 1880, to 36·12 per cent. in 1881.

Recording rain gauges.

Having regard to the importance of determining the provision to be made for rainfall in sewers and in other hydraulic works, the writer devised a recording rain gauge in the year 1878, which records the time when rain falls, the quantity of rain falling, and consequently the rate at which rain falls, and this rain gauge has been working at Croydon continuously from the year 1879 to the present time. The first results recorded by this gauge were published in Symons' British Rainfall for the year 1880, and gave the results of rainfalls occurring between March, 1879, and April, 1881, from which it will be seen that the rates of rainfall are sometimes extremely heavy, as on one occasion the rate of fall, if it had continued for 24 hours, would have been equal to a daily fall of 37·44 inches, but fortunately on this occasion the quantity falling was small, ·13 of an inch, which fell in five minutes on the 10th of July, 1880. During the thunderstorm that visited Croydon on 30th May, 1903, ·80 inches of rain fell in 15 minutes, or the rain fell at the rate of 76·8 inches in 24 hours. The total fall in this day was 1·85 inches, which fell in 2·84 hours. The maximum rate of fall exceeded the average rate† of fall by 64 times, which is the greatest rate of fluctuation that has been observed at Croydon.

Rates at which rain falls.

Rates of rainfall published by Royal Commission on Thames Sewage Discharge.

Further particulars of the rate of rainfall and the effect upon the Croydon sewers were given by the writer in evidence before the Royal Commission on Thames Sewage Discharge. In that case the rate of rain

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* Note.—The population of Rhyl is considerably increased by visitors in the summer time. The volume of sewage includes the visitors and is calculated on the permanent population only.

† The average rate in this case is the average of the last 13 years or ·05 inches per hour.

Object of Croydon sewer gaugings.

falling and the way in which the sewers of Croydon were affected by the rain were duly recorded. It should, however, be observed with reference to these observations on the Croydon outfall sewer, the gaugings of which have been carried on continuously from 1878 to 1888, was with the view of arriving at the amount of spring waters in the sewers as forming part of the yield of the drainage area of the Croydon branch of the River Wandle, which has been under the writer's observation in order to determine the quantity of water the area of chalk yielded, and also to discover the precise rate of fluctuation of the yield of water from such area from time to time. In the tables supplied to the Royal Commision on Thames Sewage Discharge of the relative number of volumes of sewage flowing, the amount of leakage or spring waters in the sewers has not been deducted, which should be the case if the true effect of rainfall on the sewage proper is to be determined.

Rain falls in a limited time.

Since the writer's Croydon recording rain gauge was put to work, several recording rain gauges have been started to work, which show that universally rain falls in a limited time, and that it is the rate at which it falls and flows off that has to be dealt with in works of sewerage and sewage disposal as in other engineering works.

Desirable that use of recording rain gauges should be extended.

The records as to the rate at which rain falls and flows off are of great importance, and it would be desirable to get these records extended all over the country.

At Southport a recording rain gauge has been at work for some time recording the rate at which rain has fallen each year, the record having been kept by Mr. Joseph Baxendell, the Borough Meteorologist. These results for four years 1898–1901 are given in the following table :—

—	1898.			1899.			1900.			1901.		
	Rain-fall. Inches.	Number of days ·01 or more fell.	Time rain fell. Hours.	Rain-fall. Inches.	Number of days ·01 or more fell.	Time rain fell. Hours.	Rain-fall. Inches.	Number of days ·01 or more fell.	Time rain fell. Hours.	Rain-fall. Inches.	Number of days ·01 or more fell.	Time rain fell. Hours.
January - -	2·62	15	73	3·73	21	77	4·30	23	89	1·58	16	33
February -	2·18	21	41	1·55	12	33	3·00	17	58	1·57	15	35
March - -	·91	10	25	1·28	11	27	·94	6	18	2·66	15	41
April - -	1·98	11	37	3·03	20	51	1·51	15	30	1·78	13	42
May - -	3·26	14	56	2·39	17	57	1·83	10	39	·97	8	24
June - -	1·85	12	32	1·56	7	25	1·69	15	38	1·71	12	29
July - -	·35	5	9	1·55	12	33	·79	7	14	1·72	9	36
August - -	5·14	17	54	1·51	12	16	6·56	15	65	2·80	15	40
September -	1·48	10	23	3·87	19	41	1·86	14	28	·86	10	21
October - -	3·46	16	55	3·09	12	53	4·57	24	61	2·92	18	43
November -	3·02	18	58	2·08	14	16	3·13	18	54	4·29	11	58
December -	2·48	23	50	2·71	16	81	3·51	23	62	3·83	21	66
Totals - -	28·73	172	513	28·35	173	510	33·69	187	556	26·69	163	468

On an average of these four years rain fell at Southport in 511·75 hours per annum, which is equal to 21·32 days in a year. The average number of rainy days in the four years was 173·75, and the average rainfall in these four years, 29·365 inches per annum. The average rate of fall, therefore, was at the rate of ·0574 inches per hour. The average quantity of the daily fall on a rainy day of these four years was ·169 inches per day, which, divided by the hourly rate of fall, shows that the time of average rate of falling in this district was 2·944 hours per day, or 176·6 minutes per rainy day. The average rate of fall per rainy day was equivalent to 613·47 cubic feet per acre, which, divided by the number of minutes in which rain fell on an average rainy day, shows that the average rate of fall at Southport was 3·47 cubic feet per acre per minute or 31,230 gallons per acre per day.

Rate of rainfall at five stations in 1902.

The following Table shows the quantity and time in which rain fell in the year 1902 at five stations in different parts of the country :—

—	Croydon. 162 feet above O.D.			Melbury Moor, Devon, 516 feet above O.D.			Timsbury, Hants. 96·4 feet above O.D.			Twyford, Hants. 139 ft. above O.D.			Southport. 42 feet above O.D.		
	Rain-fall. Inches.	No. of Days ·01 or more fell.	Time Rain fell. Hours.	Rain-fall. Inches.	No. of days ·01 or more fell.	Time Rain fell. Hours.	Rain-fall. Inches	No. of days ·01 or more fell.	Time Rain fell. Hours.	Rain-fall. Inches	No. of days ·01 or more fell.	Time rain fell. Hours.	Rain-fall. Inches	No. of days ·01 or more fell.	Time Rain fell. Hours
January - -	·670	11	26·33	3·580	18	46·14	·75	12	22·53	·88	7	17·41	2·38	18	69·3
February - -	·810	11	39·24	1·995	19	34·99	1·63	14	36·20	1·76	8	36·36	1·40	9	38·6
March - -	1·725	11	38·77	4·045	26	67·32	2·20	14	52·02	2·66	10	44·13	1·97	21	65·7
April - -	·720	10	30·05	2·340	14	35·86	1·97	13	28·57	1·75	11	28·82	1·56	13	44·9
May - -	2·500	22	72·70	2·665	23	47·78	2·43	21	71·10	2·84	20	49·15	3·39	24	74·2
June - -	3·980	19	82·13	4·425	23	93·66	3·58	18	60·53	3·85	16	58·46	1·56	15	33·4
July - -	1·220	12	32·00	3·160	16	40·97	1·41	12	28·16	1·54	10	27·04	2·37	15	51·6
August - -	3·225	20	50·83	2·765	24	48·32	3·24	19	50·09	3·33	16	44·47	2·07	21	42·6
September -	1·105	7	10·65	4·965	21	54·57	1·09	14	23·58	1·01	7	12·95	·97	15	27·7
October - -	1·440	19	49·12	5·050	22	102·65	2·01	17	57·73	2·16	11	56·95	3·01	19	84.7
November -	1·890	12	58·95	5·755	21	107·01	3·25	19	62·10	3·64	17	55·29	1·89	15	60·8
December -	1·380	11	38·58	5·060	19	112·97	1·90	11	36·86	2·27	10	37·79	2·85	14	46·5
Totals -	20·665	165	529·35	45·805	246	792·24	25·46	184	529·47	27·69	143	468 82	25·42	199	640·1

Croydon rainfall.

The rainfall at Croydon, which the writer gave to the Royal Commission on Thames Sewage Discharge for the four years 1879 to 1882, shows that the average rainfall in these years was 28·40 inches per annum; the average rainfall at Croydon for 27 years, 1876 to 1902, was 25·615 inches per annum; the average number of rainy days in 27 years was 167·37 per annum, while the number of rainy days in the four years 1879 to 1882, was 168 per annum. The quantity of rainfall on a rainy day in 1879 to 1882 was ·169 inches. It was found that in these four years the average rate of fall was ·065 inches per hour, which is equal to an average rate of 1·56 inches in 24 hours, which is a rate of fall in excess of what it has been subsequently observed. The total time that rain fell in one year on the average of these four years was therefore $\frac{28\cdot40}{1\cdot56}$ = 18·2 days, the average time the rain fell on a rainy day being $\frac{\cdot1690}{\cdot065}$ = 2·60 hours, or the rain fell on the average rainy day in 156 minutes. The quantity that fell on an average rainy day is equal to 613·615 cubic feet per acre, which quantity divided by 156 minutes, the average time of falling, equals 3·933 cubic feet per acre per minute as the rate at which on the average rain fell at Croydon in these four years.

Rate and quantity of rain at Croydon.

The rate of fall at Croydon for the 12 months ending December, 1902, was very much less than shewn by the previous published records. The average daily quantity of rain falling was at the rate of 454·62 cube feet per acre, the time of falling was extended to 192·49 minutes and the quantity was only 2·362 cube feet per acre per minute.

Rate of rainfall and quantity of rain falling at Melbury Moor.

The registering rain gauge at Melbury Moor in Devonshire was put up by the writer in a district noted for its large rainfall, and as the result of 12 months' observation ending December, 1902, it is shewn that the rain falling was 45·805 inches, which fell on 246 days, the average daily rate of fall being ·1862 inches. The hourly rate of fall is ·0578 inches, which divided into ·1862 gives 3·220 hours per day as the average time of falling, or 193·2 minutes per rainy day. The average rate of fall was 675·91 cube feet per acre per day falling at the rate of 3·498 cube feet per acre per minute.

The records at Timsbury and Twyford are the results of observations that have been made at the South Hants Water Company's works, the directors of this water company having authorised the writer to put up recording rain gauges and other apparatus at each of their pumping stations, so that an accurate record of the rate and quantity of rain falling and the amount of rain which percolates into the ground might be ascertained.

Rate of rainfall and quantity flowing off at Timsbury.

The results of the 12 months' records at Timsbury Pumping Station for the year ending December, 1902, shew that the quantity of rain falling in the year was 25·46 inches, the number of days on which rain fell 184, and the average quantity falling per rainy day ·1384 inches. The hourly rate of fall is ·0481 inches, which divided into ·1384 equals 2·88 hours per day or 172·6 minutes per rainy day. The total quantity falling each rainy day was 502·39 cube feet per acre, and the average rate of fall was 2·911 cubic feet per acre per minute.

Rate of rainfall and quantity of rain falling at Twyford.

The results of the 12 months' records at the Twyford Pumping Station of the South Hants Water Works during the same period as at Timsbury are as follows :—The rain falling was 27·69 inches, the number of rainy days 143, the average rate of fall per rainy day ·1936 inches. The hourly rate of fall is ·0591 inches, which divided into ·1936 equals 3·276 hours per day, or 196·6 minutes per rainy day. The rate of fall was 3·897 cubic feet per acre per minute.

Rate of rainfall and quantity of rain flowing off at Southport.

The results of the 12 months' records taken with a Halliwell Recording Rain Gauge at Southport have been supplied to me by Mr. Joseph Baxendell, the Borough Meteorologist, and the observations are taken at the Fernley Observatory, Southport. The rain falling in 12 months ending December, 1902, was 25·42 inches, and it fell on 199 days. In this case the average daily quantity of rain falling on a rainy day was ·1277 inches, which is equal to 463·55 cube feet per acre; the hourly rate of fall was ·0397 inches. The average fall took place in 3·217 hours per rainy day or in 193 minutes each rainy day, and the average quantity was 2·4 cube feet per acre per minute. It will be seen from the previous records that the rainfall in this district, as in others during the year 1902, is remarkable for the slow rate at which rain has fallen.

Manchester sewer gaugings and rate of rainfall.

For the year 1899, the writer worked out the Manchester sewer gaugings for as much of the year as the observations were perfect, and the results are given in Table No. 4. He also worked out from the rainfall diagrams the rate at which rain fell at the Sewage Outfall Works at Davyhulme in this year, the figures of which are given in the following Table :—

Manchester rainfall, year 1899.

MANCHESTER RAINFALL.

Month.	Rainfall Inches.	Time of falling. Hours.	Number of days on which ·01 or more fell.	Maximum Falls.	
				Rate of fall per hour. Inches.	Rate of fall per 24 hours. Inches.
1899. January	3·000	58·93	17	·100	2·400
February	·915	25·58	11	·120	2·880
March	1·510	38·75	9	·060	1·440
April	2·380	49·08	16	·210	5·040
May	2·390	67·42	14	·180	4·320
June	1·620	19·58	8	·440	10·560
July	1·750	40·25	9	·264	6·336
August	·870	23·33	7	·060	1·440
September	5·170	63·75	18	·150	3·600
October	3·045	52·83	13	·120	2·880
November	1·035	14·50	14	·390	9·360
December	2·530	55·93	14	·115	2·760
Total	26·215	509·93	150	—	—

Manchester sewer gaugings. Table No. 4.

Percentage of rain flowing off.

Percentage of rain and subsoil water, Manchester sewers.

In Table No. 4 the results of certain sewer gaugings of Manchester are given, and which show the total quantity of sewage gauged within the periods set out, the volume due to rainfall, the depth of rain flowing off, the actual rainfall at the time, and the percentage of rain flowing off. It will be observed from the results given in this table that not more than 40 per cent. of the rain falling on the district actually flowed off by the sewers at this particular time, that is exclusive of subsoil water, and if it is assumed that the subsoil water in the case of Manchester is contributed solely from the Manchester area the actual quantity of rain flowing off by the sewers as rain and subsoil water was about equal to 78 per cent. of the actual rainfall.

Comparison of time rain fell at Manchester and Southport.

Correction of Manchester rates of fall.

Average rates of rainfall.

It will be seen from the Rainfall Table, that the time rain fell in Manchester did not differ from the time rain fell at Southport in the same year, the rainfall recorded being heavier at Southport than at Manchester. The rainfall at Manchester was really heavier in this year than given by the recording rain gauge, the mouth of which is at a higher level above the ground surface than an ordinary rain gauge and consequently records a smaller volume of rainfall. The rain collected by the recording rain gauge was 26·215 inches in the year, and the number of rainy days 150, but the actual rain collected in a rain gauge near the level of the ground at the same place was 28·35 inches and it fell upon 161 days. If the time of rain falling is taken from the recording gauge and the quantity falling from the ordinary rain gauge we have the record that the rain fell upon 161 days which was equal to ·176 inches per rainy day. The rate of fall was ·0556 inches per hour, which divided into ·176, the average fall on a rainy day, equals 3·17 hours per day, the average time of rain falling or 190 minutes per rainy day, and the rate of fall was equal to 3·36 cubic feet per acre per minute. Of course the observations of this one year at Manchester do not give what is the average result as the rainfall in 1899 was below the average. The average rainfall of Manchester taken at various elevations may be taken at 32½ inches per annum falling upon 186 days in the year, giving a rate of ·1742 inch per rainy day with an average hourly rate of fall of probably ·067 inch per hour and falling in about 156 minutes per day, which is equal to an average rate of fall of 4 cubic feet per acre per minute.

Area draining to Manchester sewers.

Quantity of rain flowing off by Manchester sewers.

The fluctuation of the flow in the sewers in the case of Manchester is very materially modified owing to the extent of the area contributing rainfall, and which is stated to be 9,611 acres, by which some part of the flow in the sewers is deferred, and the flow rendered more uniform. If it is assumed that the rain passing into the sewers comes only from the actual area of Manchester, it was observed in the year 1899 as much as 2 cubic feet per acre per minute at times actually flowed off. There is a record which shews that on the 6th August, 1900, the rate of flow of the sewage and rainfall in the Manchester sewers was at the rate of 2·608 cube feet per acre per minute, of which 2·311 cube feet per acre per minute was due to rainfall.

Manchester is in a position in which nothing like the same proportional provision would require to be made in the sewers as in towns of less extent with shorter lines of sewers.

Rate of flow off by Manchester sewers.

Time rain flows off in Manchester sewers.

Subsoil water in Manchester sewers.

Leakage into Manchester sewers.

The actual rate of flow off in Manchester was shewn by the results recorded between the 10th July and 12th September, 1899, when the rain is recorded as having fallen in 151 hours and 10 minutes; the actual time it took the rain to flow off was 1,008 hours, or the rain falling in one hour took 6·65 hours to flow off, and the consequence of this long time in flowing off is to make the flow very much more equable and the effect of rainfall is not so serious in the sewers of Manchester as in the sewers of some other districts of smaller extent. Of course in the gaugings of the sewage of Manchester there is a certain amount of subsoil water combined with the sewage which tends to make the fluctuation in the sewers caused by rain less than otherwise would be the case. This was pointed out by the writer to the Rivers Committee of the Manchester Corporation in a report made to them in March, 1900, wherein it was stated that: "There is no doubt that there is a considerable leakage of subsoil water into the sewers and drains of Manchester, as this is very clearly evidenced by the fact that when the springs are low the minimum flow in the sewers on the same days of the week fall very much lower than in the periods when the springs are high, for example, during last year the springs were lowest at the beginning of

December and highest at the end of February. It will be observed, taking dry Sundays, that the minimum flow of the sewers on the 10th December was 1,497 cubic feet per minute, whereas on the 9th July under similar circumstances it was 1,951 cubic feet per minute, a difference of 454 cubic feet, or about four million gallons per day more leakage into the sewers in July than in December."

Volume of water supply and leakage into sewers, Manchester.

It appears from a report of the Rivers Department of the City of Manchester descriptive of the treatment of Manchester sewage that the volume of the water supply of Manchester is estimated at 29 gallons per head per day of the population, of which 16 gallons are used for domestic purposes, 13 gallons being used for trade and other purposes. The dry weather flow of the sewage of Manchester for the year ending the 27th March, 1901, was 45½ gallons per head per day, which is made up therefore of 16½ gallons per head per day of leakage, which was rather more than the domestic water supply.

Leakage, Manchester more than domestic water supply.

Croydon sewer gaugings.

For a number of years the writer has been conducting gaugings at Croydon and the neighbourhood with a view to ascertain the quantity of water that was contributed by the chalk area of the Croydon Branch of the River Wandle. These gaugings were carried on from 1876 to 1888, when the writer found from the results of the gaugings and observations a mode of calculating the volume of underground water from the levels of the subsoil water when it was no longer necessary to continue the gaugings, and which became more and more complicated owing to additional sources of water supply being brought into Croydon. During these gaugings, amongst other sources of water it became necessary to gauge the sewers of Croydon having regard to the large amount of subsoil water which these sewers carried away. The volume of subsoil water in the Croydon sewers is in excess of the actual rain falling on the sewered area. This is due to the position of the sewers, which are located in a valley below a large drainage area extending for a considerable distance above the town.

Subsoil water in Croydon sewers.

Croydon gaugings continuous.

The whole of the observations of Croydon were carried on continuously with a view to determine the amount of spring water in the sewers, but having got the whole of the gaugings automatically recorded in diagram form it was only a question of abstracting any information necessary for ascertaining the effects of rainfall on the sewers, and with this view the writer has at your request investigated the results of seven years' gaugings from 1880 to 1886 inclusive.

Mode in which Croydon sewers were gauged.

The mode in which these Croydon gaugings were made was by means of a recording instrument with clock arrangement, which either recorded on a diagram the depth of water flowing in the sewer or the depth flowing over a measuring overfall gauge weir. The flow in the sewer was ascertained at every depth of flow, and these results were invariably checked once a week or more often with a full day's flow over the gauge weir. The gaugings have all been worked out for every hour of the day, and the record, with the exception of one or two days, is complete for the whole period.

Gaugings made in writer's private capacity.

It should also be observed with reference to these gaugings, that they have been made and worked out in the writer's private capacity and at his own cost, and the object was with a view to enable the volume of spring water in the sewers from time to time to be ascertained. At the same time the quantity of water daily supplied to Croydon was furnished to him by the Local Authority as this water is pumped daily into the district for the ordinary supply, and there was no large storage to interfere with the results, and therefore the daily quantity can be readily ascertained, and in the Croydon gaugings the daily volume of water supply is taken as representing what would be the ordinary dry weather flow of sewage, thus excluding all leakage from the calculations.

Dry weather flow at Croydon, taken as the volume of water supplied.

Distribution of Croydon water supply.

The whole of the Croydon water supply did not find its way to the Croydon outfall sewer, but was in part distributed to other sewers, and after careful investigation it was found that as near as possible 80 per cent. of the whole of the daily supply of water was distributed to this particular outfall.

Water supply does not all go to the sewers.

It should be observed that a part of the water supply never enters the sewers, notably all that part that is used in watering streets and gardens. On the other hand, a certain volume of liquid enters the sewers that did not originate in the water supply, such as rain water collected for washing, which is sparsely used in the district, the liquids brought into and manufactured within the district used for drink and food.

Effect of leakage may be calculated

Effect of leakage in diminishing fluctuation.

It should be observed, with reference to the leakage into sewers, that the dry weather flow and the fluctuations of flow in the sewer without leakage being known, the relative fluctuation of flow due to the addition of subsoil water can be readily calculated, as, for example, the ordinary dry weather fluctuation of flow in a limited district as between the period of maximum flow and mean flow would be about $2\frac{1}{2}$ to 1, but if we add a volume of subsoil water equal to the average dry weather flow, the ratio of fluctuation would be reduced to $1\frac{3}{4}$ to 1, but the volume of sewage to be treated would be doubled.

No storm overflows in Croydon sewers

At the time these Croydon sewer gaugings were made, there were no storm overflows in the sewers, and therefore the whole of the sewage and rain went down to the point of outfall and was gauged.

Question of construction of sewers differs from that of sewage treatment

Inadequate provision made for rainfall in sewers.

Provision for rain in London sewers.

Days of rainfall.

Law governing rate of rainfall.

Rain at times greatly exceeds the average.

Rate of rainfall, Croydon, and effect on sewers. July, 1880.

Rate of rainfall, Croydon, and effect on sewers October, 1880.

The question of the construction and the size and fall of sewers is one rather different to that referring to the disposal of sewage. In the construction of sewers the sewers will have to carry the rain which enters them at the rate at which it falls and flows off, but the disposal of sewage has only reference to the ultimate volume to be treated, provided means of storage are provided for the sewage until it can be treated. It will appear with reference to the question of the construction of sewers that often very inadequate provision is made for the reception of rainfall, as some fixed amount has been determined upon to be admitted to the sewers in the space of the 24 hours, totally regardless of what is the law which governs the rate at which rain falls and flows off. Consequently, very inadequate provision has been made in many systems of town sewers for dealing with the rainfall, and as a result serious flooding from the sewers occurs. For example, in London the largest quantity of rain proposed to be admitted to the sewers was to be at the rate of a quarter of an inch in depth spread over 24 hours. This it will be observed is only equal to about 0·63 of a cubic foot per minute from an acre, a quantity not one-sixth as much as the average rate at which rain falls. It should be observed that the rain falls in a limited time, and if all the time rain is falling is added together, in the course of a year it will not amount to more than 18 to 27 days, the smaller number of days occurring in the dry districts and the larger number in the districts having heavy falls of rain. It is not the absolute quantity of rain that falls, but the rate at which rain falls and flows off, which is the difficulty that engineers have to contend with. As a rule, in districts in which there is the heaviest fall of rain, the rain is spread over a greater length of time than in those districts in which the rainfall is smallest, and often in the driest years the sharpest rainfalls occur. The law which governs the rate of fall has not been fully determined, but it is probably proportional to the average fall on a wet day or the annual rate of fall divided by the number of days upon which it falls. The figures given as to the rates at which rain falls shew the average rates of fall, but of course there are times when the rate of fall greatly exceeds the average and when the actual flow off the surface greatly exceeds the average rate of the fall of rain. The maximum rate of rainfall at Croydon exceeded the average by 24 times, as on the 10th of July, 1880, the fall was at the rate of 37·44 inches per day, which divided by 1·56 inches per day, the average rate of fall, equals 24 times the mean rate of fall. The quantity of rain that fell on this occasion, however, was small, and the time short, and the time of day when it fell was between 7 and 8 p.m., when the mean flow in the sewers was only increased over one hour, 3·84 times, the total rainfall in that day being only ·350 inches. On the 9th of October, 1880, 2·12 inches of rain fell at Croydon in the day; the greatest rate of fall was at the rate of 10·8 inches per day, which occurred between 2 and 3 a.m., which was equal to 6·92 times the mean rate of fall, but the flow in the sewers increased for one hour to 8·97 times the mean dry weather flow, and the rain alone flowing off the surface into the sewers was at the rate of a fall of 2 inches in depth per day.

Rate of rainfall, Croydon, and effect on sewers December, 1881.

On the 19th December, 1881, the flow in the Croydon sewers increased for an hour to 10·76 times the average flow, the rainfall in the day being ·595 inches; its greatest rate of falling was 10·26 inches in 24 hours, which occurred between 6 and 7 a.m., and the rate exceeded the average by 6·576 times. The rain flowing off the surface into the sewers was at the rate of 2·25 inches in depth per day.

Rate of rainfall, Croydon, and effect on sewers. October, 1882.

On the 27th October, 1882, the flow in the Croydon sewers increased for one hour to 11·56 times the mean flow, the rainfall recorded in the day being ·95 inches, the greatest rate of fall 3·60 inches in 24 hours, which occurred between 6 and 7 a.m., and the quantity of rain that flowed off the surface was at the rate of 2·36 inches in depth per day.

Rate of rainfall, Croydon, and effect on sewers. September, 1883.

On the 10th September, 1883, the flow in the sewers increased for one hour to 13·31 times the mean flow, the rainfall in the day being ·655 inches, the greatest rate of fall being at the rate of 6 inches in 24 hours, which occurred between 4 and 5 a.m. The quantity of rain that flowed off the surface was at the rate of 3·09 inches in depth per day.

Rate of rainfall, Croydon, and effect on sewers. January, 1884.

On the 26th January, 1884, the mean dry weather flow in the sewers was increased 12·11 times, the rainfall in the day being ·86 inches, and the greatest rate of fall being at the rate of 6·24 inches in 24 hours, which occurred between 7 and 8 p.m., and was at the rate of four times the mean rate of fall. The quantity of rain that flowed off the surface was at the rate of 2·20 inches in depth per day.

Rate of rainfall, Croydon, and effect on sewers. June, 1885.

On the 8th June, 1885, the flow in the sewers increased for one hour 9·38 times the mean dry weather flow. The rainfall on the day was ·76 inches. The greatest rate of fall was at the rate of 11 inches in 24 hours, which occurred between 6 and 7 a.m. The flow off of rain only was at the rate of 1·52 inches in depth per day.

Rate of rainfall, Croydon, and effect on sewers. May, 1886.

On the 12th May, 1886, the flow in the Croydon sewers increased for one hour 13·78 times the mean dry weather flow. The rainfall in the day was 1·25 inches. The greatest rate of fall was at the rate of 32·23 inches in 24 hours, which occurred between 7 and 8 a.m. The flow of rain only off the surface was at the rate of 2·23 inches in depth per day.

Maximum and minimum times of flow in Croydon sewers. Times of maximum and minimum flow in Manchester sewers.

The flow in the Croydon sewer was found to be greatest between the hours of 11 and 12 a.m., and least between the hours of 3 and 4 a.m. At other places the times of greatest and least flow vary. In large towns it falls much later in the day, as, for example, in Manchester sewers, the maximum occurs between 1 and 2 p.m., while the minimum occurs about 6 o'clock in the morning, except on Sundays, when the minimum flow occurs between 8 and 9 a.m. and the maximum between 2 and 3 p.m.

Time of day when rain falls affects the rate of fluctuation of flow.

Sewers are affected more or less by the time of day at which rain falls; if it falls when the sewers are at the period of maximum flow it affects the mean flow more than if the rain falls when the sewers are carrying their least flow. In small areas the maximum flow of sewage proper will be 2½ times the mean flow, while the minimum flow will be one-third the mean flow.

The following Table has been constructed and used by the writer for calculating the volume of sewage flowing in sewers within small districts having an outfall sewer of limited length:—

Table from which the dry weather flow of sewage at any time of the day may be calculated. To use this Table, multiply the total daily flow by the figures given, and divide by 100, and the answer will give the quantity flowing per minute.

For example, assuming the average quantity is 100,000 cubic feet per day at the maximum time of discharge, the quantity $= \frac{\cdot 1720 \times 100{,}000}{100} = 172$ cube feet per minute.

11 p.m.	·0420	Eight minimum hours.
12 midnight	·0403	
1 a.m.	·0320	
2 a.m.	·0279	
3 a.m.	·0269	
4 a.m.	·0269	
5 a.m.	·0346	
6 a.m.	·0455	
7 a.m.	·0637	Eight maximum hours.
8 a.m.	·0743	
9 a.m.	·0864	
10 a.m.	·1190	
11 a.m.	·1561	
12 noon	·1720	
1 p.m.	·1420	
2 p.m.	·1050	

3 p.m.	·0800	Eight mean hours.
4 p.m.	·0684	
5 p.m.	·0585	
6 p.m.	·0571	
7 p.m.	·0580	
8 p.m.	·0542	
9 p.m.	·0523	
10 p.m.	·0436	

At different times and in various places gaugings of the sewers have been made by the writer, from which the following examples are taken.

Gaugings of South Norwood sewers in January, 1866.

Gaugings of South Norwood sewers in July and August, 1866.

Indication of leakage.

In the year 1866 the writer caused the South Norwood outfall sewer in the Croydon district to be gauged as the sewage was discharged upon the sewage farm. The result of the average gaugings in dry weather in January of this year showed that the maximum flow was 31·09 cube feet per minute extending over one hour. The minimum flow was 14·57 cube feet per minute extending over one hour and the mean flow 20·37 cube feet per minute, the ratio of maximum flow to minimum flow being as 2·13 to 1 and the ratio of maximum flow to mean flow was as 1·53 to 1. The period of maximum flow occurred between the hours of 10 a.m. and 11 a.m. and of minimum flow between the hours of 7 a.m. and 8 a.m. The supply of water in this district was, at the time, not constant, and it was found that in consequence the hour of maximum dry weather flow varied considerably. In July and August, 1866, the South Norwood outfall sewer was again gauged when the dry weather flow was found to be 14·29 cube feet per minute on the average, or considerably less than the dry weather gaugings in the preceding January, indicating that there was a certain amount of leakage into these sewers. The maximum sewer gauging in July and August, 1866, extending over one hour was 23·91 cube feet per minute, which occurred between 9 a.m. and 10 a.m. The minimum sewer gauging extending over one hour at the same period was 9·11 cubic feet per minute. The ratio of maximum flow to minimum flow was as 2·62 to 1 and the ratio of maximum flow to mean flow was as 1·67 to 1.

Gaugings of South Norwood sewers, June, 1870.

In the month of June, 1870, a series of gaugings were made of the outfall sewers of Croydon and South Norwood, together with the flow off the respective sewage farms. The mean average dry weather flow at the South Norwood outfall extending over a week gave 17·6 cubic feet per minute as the average rate of flow. The average dry weather flow extending over one hour varied from a maximum of 61·28 cubic feet per minute which occurred between 3 and 4 p.m. to an average minimum flow of 8 cubic feet per minute, which occurred between 6 and 8 a.m. The ratio of average maximum flow to average minimum flow in this case was 7·66 to 1, while the ratio of maximum flow to mean flow varied as 3·48 to 1.

Gaugings of South Norwood sewers, December, 1870, and January, 1871.

Indication of leakage.

Table No. 5. Gaugings of South Norwood sewers.

In December, 1870, and January, 1871, the South Norwood outfall sewer was again gauged for one week, and the average dry weather flow was found to be 29·64 cube feet per minute. The average maximum flow extending over one hour was 52·66 cube feet per minute, which occurred between 3 p.m. and 4 p.m. The minimum flow extending over one hour was 17·43 cube feet per minute, which occurred between 5 a.m. and 6 a.m. The ratio of average maximum flow to average minimum flow was as 3·02 to 1 and the ratio of maximum flow to mean flow 1·78 to 1. The increase in the minimum flow at this period indicates that there was a certain amount of leakage in the sewers which reduces the ratio of maximum flow to mean and minimum flow. There were no storm overflows in connection with the South Norwood sewers at the time the gaugings were made, and the district being of a more or less impermeable character, the volume of rain entering the sewers is very considerable, having regard to the extent of the district and the population draining to the sewers. It will be seen from Table No. 5 that at times the mean dry weather flow of sewage has been very considerably increased by the effect of rainfall. The table shews the effect of rain on the sewers on days of heavy falls. The dry weather flow in the sewers, ascertained from the sewer gaugings on dry days, taken at the same period as the wet weather gaugings; the average and the maximum rate of flow in the sewers; the total volume of sewage in the sewers on each of the rainy days; the total flow of actual rainfall in the sewers on each rainy day; the number of volumes the maximum flow extending over one hour exceeded the mean flow. The number of hours each rainy day the flow in the sewer exceeded three, four, five and six times the dry weather flow in the sewer; the total volume of sewage in excess of three, four, five and six times the mean dry weather flow. The effect of the rainfall in this case was most materially influenced by the exceptionally heavy fall and flow off which occurred on the 13th January, 1866.

Gaugings of Warwick sewers, September, 1866.

In September, 1866, the writer had a series of gaugings taken of the two outfall sewers of the town of Warwick, when it was found that at the Castle Park outfall, the flow of the sewage varied from a maximum of 57·18 cubic feet per minute between the hours of 12 and 1 p.m., to a minimum of 12·47 cubic feet per minute between the hours of 3 a.m. and 5 a.m. At this outfall the ratio of maximum to minimum discharge was as 4·585 to 1, and the ratio of maximum discharge to mean discharge was 1·753 to 1. At the Stratford Road outfall sewer of Warwick the maximum flow in the sewer was 79·82 cube feet per minute, which occurred between the hours of 11 and 12 a.m., while the minimum flow in the sewer was 57·12 cube feet per minute, which occurred between the hours of 12 and 1 a.m. In this case the ratio of maximum to minimum discharge was as 1·397 to 1, while the ratio of maximum discharge to mean discharge was as 1·173 to 1. These sewer gaugings of Warwick shew that there was leakage going on, especially in the sewers connected with the Stratford Road outfall. The total dry weather flow of the sewage was 905,900 gallons per day, contributed by a population of about 10,780 persons, the mean dry weather flow being equal to 84·04 gallons per head per day. The flow of sewage in this case was largely increased by reason of the admittance of the waste water from a gelatine manufactory in which large volumes of water were used.

Gaugings of Rugby sewers in 1868.

In the dry and warm months of June and July, 1868, the writer caused the outfall sewer of the town of Rugby to be gauged, when the average maximum flow over one hour was found to be 107·0 cubic feet per minute, and the average minimum flow over one hour, was 12·57 cubic feet per minute, the ratio of maximum flow to minimum flow being as 8·51 to 1. The mean flow in the sewer was 45·86 cubic feet per minute, the ratio of maximum flow to mean flow being as 2·33 to 1. The dry weather flow of sewage was equal to 50 gallons per head per day.

Gaugings of Rugby sewers in 1869.

In April, 1869, these sewers of Rugby were again gauged, when the maximum flow was found to be 81·77 cubic feet per minute, the minimum flow 22·32 cubic feet per minute, and the mean flow 42·61 cubic feet per minute, the ratio of maximum flow to minimum flow being as 3·66 to 1 and the ratio of maximum flow to mean flow as 1·92 to 1. These gaugings shew, when compared with the former gaugings, that a certain amount of leakage was present in these sewers at the time of this gauging, although the mean flow had actually diminished but the minimum flow had increased.

Gaugings of Atherstone sewers in 1880.

The writer caused the sewers of the small town of Atherstone in Warwickshire to be gauged in the months of August and September, 1880, at a time before there was a public supply of water, when it was found that the maximum flow of sewage was 9·168 cubic feet per minute, which occurred beween 10 a.m. and 11 a.m., while the minimum flow was 1·122 cubic feet per minute, which extended over a period from 10 p.m. to 5 a.m. The average mean flow of the sewers at the time was 3·904 cubic feet per minute and the ratio of maximum to minimum dry weather discharge varied as 8·17 to 1, and the ratio of maximum to mean flow varied as 2·35 to 1.

Friern Barnet sewage works, designed in 1883.

The Friern Barnet Sewage Works, which were designed by the writer, were the earliest works in this country to be brought into operation for the purposes of bacteriological treatment of sewage. These works were designed in 1883, and the actual construction of the works commenced in December. 1885. They were in full operation during the whole of the year 1887, and Dr. Hugh Stott, the medical officer of health of the district, stated in his Annual Report for the year 1887, referring to his visits to several sewage works—"From my personal inspection I certainly think none of the works or the systems of treatment were so good as those of Friern Barnet. During the year the effluent from the works has been very good. I have taken forty samples in all at different times and analysed them. The result has been satisfactory." It should be observed that these Friern Barnet Works had been in full operation for at least twelve months before the valuable experiments on Sewage Filtration of the State Board of Health of Massachusetts had been brought into operation, and which were commenced on the 10th January, 1888.

Gaugings, Friern Barnet sewers in 1887.

At Friern Barnet the writer had a series of sewer gaugings made in the year 1887. It should be said that in this district there were great complaints at the time of the insufficiency of the Public Water Supply and the supply was of an intermittent character. In the whole month of February, 1887, the mean average dry weather flow was 10·96 cubic feet per minute, the average maximum flow 15·14 cubic feet per minute, which occurred between 12 noon and 1 p.m., and the average minimum flow 8·50 cubic feet per minute, which occurred between the hours of 1 a.m. and 2 a.m. The extreme maximum dry weather flow was 21·89 cubic feet per minute and the extreme minimum dry weather flow was 4·21 cubic feet per minute. The ratio of the average maximum flow to the average minimum flow was as 1·78 to 1, and the ratio of the average maximum flow to mean flow was as 1·38 to 1. The ratio of extreme maximum flow to extreme minimum flow was as 5·2 to 1. For 17 dry days spread over the months of August, September and October, 1887, the mean maximum flow was 13·81 cubic feet per minute, and the mean minimum flow was 4·52 cubic feet per minute, the mean dry weather flow being 8·48 cubic feet per minute. The extreme maximum dry weather flow was 27·4 cubic feet per minute and the extreme minimum flow was 2·0 cubic feet per minute. The ratio of the average maximum flow to the average minimum flow was as 3·06 to 1; the ratio of the average maximum flow to mean flow was as 1·63 to 1. The ratio of the extreme maximum dry weather flow to minimum dry weather flow was as 13·7 to 1, while the ratio of extreme maximum dry weather flow to mean dry weather flow was as 3·23 to 1. For 19 wet days extending over the months of August, September and October, 1887, the average flow of sewage and rain at Friern Barnet was 18·85 cubic feet per minute, the dry weather sewage being 8·48 cube feet per minute at the same period of the year, but in judging these respective quantities it should be borne in mind that the dry weather flow of sewage of Friern Barnet was at the time very small owing to deficient water supply. The population of Friern Barnet using the outfall works in 1887 was given as 6,881. In February of that year the dry weather flow of sewage was 14·33 gallons per head per day, while in August, September and October the dry weather flow of sewage was but 11·09 gallons per head per day. The volume of sewage at Friern Barnet was not more than a fourth of the volume ordinarily met with in towns, and the sewage as a consequence is very strong, and when rain falls, as judged by the number of volumes of increase, will be much greater in such a district than in districts having a much larger volume of sewage.

Table No. 6. Gaugings Friern Barnet sewers.

Table No. 6 gives the results of 19 wet days gauging at Friern Barnet in the year 1887. The Table shews the rainfall in the district, the average dry weather flow in the sewer, the average flow in the sewers each wet day, the maximum flow in the sewers each wet day for a period extending over one hour, the number of hours per rainy day when the volume of flow in the sewers exceeded three, four, five and six times the mean dry weather flow, the number of volumes the maximum flow over one hour exceeded the mean flow, the total flow in the sewer each rainy day, the total dry weather flow, the flow in the sewer due to rainfall each of the rainy days, and the volume of sewage in excess of three, four, five, and six times the mean flow.

Increased flow due to rain in Friern Barnet sewers.

It will be seen from the figures that the increased flow due to rain in these selected wet days only increased the mean dry weather flow in the sewer 2·22 times, but if the dry weather flow of sewage had been four times as great, the increase due to rainfall would have been about one half of the flow of sewage.

Gaugings of Pontefract sewers in 1900.

In April, 1900, the writer caused a series of sewer gaugings of the outfall of Pontefract to be made, when it was found that the average dry weather flow of sewage was 38·99 cubic feet per minute, the maximum flow was 49·79 cubic feet per minute, which occurred between the hours of 11.30 a.m.

and 12 noon. The minimum flow was 29·14 cube feet per minute, which occurred between the hours of 4 and 4.30 a.m., the ratio of maximum flow to mimimum flow in this case being as 1·709 to 1, while the ratio of maximum flow to mean flow was as 1·277 to 1.

Particulars of Croydon sewers.

The following figures give for seven years the population draining to the Croydon outfall sewer, which was gauged, and the average daily volume of the flow in the sewers, the average daily volume of the sewage in gallons per head, and the average daily volume of water supply and the average daily supply per head of the population, which is taken as the dry weather flow in the sewers.

Year.	Population draining to sewer middle of year. Persons.	Average daily volume of sewage flowing in sewers. Gallons.	Average flow of sewage. Gallons per head per day.	Average flow in sewer due to water supply. Gallons.	Water supply in sewers. Average flow per head per day. Gallons.	Area in acres contributing rain to the sewers.
1880 - - -	46,128	4,795,470	104·0	1,975,680	42·8	317·68
1881 - - -	47,645	6,591,600	138·3	1,950,390	40·9	328·13
1882 - - -	49,078	4,889,970	99·6	1,863,630	38·0	338·00
1883 - - -	50,511	5,887,260	116·6	1,871,370	37·0	347·87
1884 - - -	51,944	3,596.670	69·2	1,807,740	34·9	357·74
1885 - - -	53,378	3,242,430	60·7	1,747,800	32·7	367·62
1886 - - -	54,810	4,011,300	73·2	1,730,250	31·6	377·48

It will be observed that in these seven years the volume of water supplied to the district, as measured by the volume supplied per head per day, has materially diminished. This is due to an improvement in water fittings, to more adequate inspection, and, as a consequence, the rate of fluctuation of flow in the sewers due to rainfall will have increased in the course of these years.

It has already been stated that in order to arrive at the volume and effect of the rainfall on the flow in the Croydon sewers, the whole of the water supply and leakage into the sewers had been deducted on each day when it rains, and that which remains in the sewer is taken as the product of the rainfall.

It should be noted that the Croydon sewers have all been reported to have been reconstructed since the year 1875, when the last epidemic of fever occurred in Croydon, and that the writer has not had anything to do professionally with Croydon public works since the year 1872, or over 30 years ago. The sewers of Croydon are now more leaky than before their reconstruction, simply because they are put at a greater depth in the subsoil water, which is an advantage from a sanitary point of view as the leakage is likely to be more or less always inwards, which was not the case formerly, and which, of course, is a great improvement having regard to the fact that the principal part of the public water supply of Croydon is procured from wells sunk in porous strata in the centre of the town and in the midst of the sewers.

Area per head of population at Croydon contributing.

In the case of Croydon outfall, the actual area contributing rain to the sewers has been ascertained by the writer to be equivalent, as near as possible, to 300 feet for each head of the population contributing to the sewers; but in districts in which no provision is made for the exclusion of surface water the area will be greater, and in districts in which there is an entire separation of rainfall from the sewers the area will be less than in Croydon. The total drainage area to the Croydon outfall sewer which has been gauged was, at the time these gaugings were made, 1,990 acres in extent, but the actual area contributing rainfall is considerably less, having regard to the porosity of the ground at Croydon and the provision which is made for conveying away the surface water.

Tables Nos. 7 to 22. Croydon sewer gaugings.

The Tables Nos. 7 to 22 give the results of seven years' gaugings of the Croydon sewer.

Tables Nos. 7 to 13. Croydon sewer gaugings.

Flow in sewer in rainy day, Croydon.

Tables Nos. 7 to 13 give yearly the results of the sewer gaugings for the years 1880 to 1886, and show the quantity of rain that fell, the number of days on which rain fell each month, the number of days each month on which the sewers were affected by the rainfall, the depth of rain flowing off by the sewers each month, the average flow in the sewer on the average each month in cube feet per minute, the flow in the sewer each month due to leakage, in cube feet per minute, the dry weather flow in the sewer which is taken as being equal to the water supplied to the district in cube feet per minute, the average flow in the sewer due to rainfall in each month in cube feet per minute when spread over every day in the year. To get at the quantity of rainfall that has to be dealt with on a rainy day the quantity given must be multiplied by the number of days in the month or year and the result divided by the number of days in the period in which the sewers are affected. Thus in the year 1880 the average flow in the sewer on a rainy day will be $\frac{29{\cdot}04 \times 366}{136} = 78{\cdot}15$ cubic feet per minute.

The Tables also shew the number of days in which the flow exceeded one and a-half, two, three, four, five and six times the mean flow for one hour, the actual maximum volume each month that the flow for one hour exceeded the mean flow, and the mean number of volumes each month that the flow exceeded the mean flow in each month and year.

Table No. 14. Croydon sewer gaugings.

Table No. 14 gives a summary of the seven annual tables Nos. 7 to 13. There has been added to it a column which shows the percentage of rainfall flowing off by the sewer. The total flow off of rainfall in these seven years was but 11·68 per cent. of the dry weather flow of the sewage.

Tables Nos. 15 to 21. Croydon sewer gaugings.

Tables Nos. 15 to 21 give each year for seven years the gaugings of the sewers on all the days in the year on which a heavy rainfall occurred. The tables shew the date when a heavy fall of rain occurred, the quantity of rain that fell in the day, the average flow in the sewer on the days of heavy rain, including leakage, the flow in the sewer due to leakage, the average dry weather flow or the volume of the water supplied to the district, the maximum flow in the sewer due to rainfall exclusive of leakage, the number of hours each day when the flow in the sewer exceeded three, four, five and six times the dry weather flow or the average water supply, the number of volumes the maximum flow extending over one hour exceeded the mean flow, the total flow in the sewer exclusive of leakage, the total flow in the sewer in excess of three, four, five and six times the dry weather flow, the discharge of the sewer in cube feet per acre per minute at the time of maximun flow, including leakage, the discharge of the sewer in cube feet per acre per minute exclusive of leakage, and the discharge of the sewer in cube feet per acre per minute due exclusively to rainfall.

Table No. 22. Gaugings Croydon sewers.

Proportion of flow exceeding certain quantities.

Table No. 22 is a Summary of the Tables Nos. 15 to 21, and in addition to giving the actual quantities of sewage in time of heavy rainfall in excess of three, four, five, and six hours, the average dry weather flow giving the percentage of the flow on all the days of heavy rain that the quantity exceeded three, four, five and six times the average dry weather flow. From this table it will be seen that on an average of seven years' gaugings of all the heavy rainfalls the quantity in excess of three times the dry weather flow was only 16·22 per cent.; the quantity in excess of four times the dry weather flow was but 9·58 per cent.; the quantity in excess of five times the dry weather flow was but 5·34 per cent., and the quantity in excess of six times the dry weather flow was under three per cent.

Table No. 23. Croydon sewer gaugings.

Table No. 23 gives the dry weather flow of the Croydon outfall sewer at every hour of the day for every day of the week in all the dry days of the year 1880. The line upon which the figures rest is the base line for the diagrams above, which shew the fluctuation for every day of the week and at every hour of the day.

Table No. 24. Croydon sewer gaugings.

Table No. 24 gives the complete gaugings of the Croydon outfall sewer in round figures for every day in the year 1881, this year having been selected as having nearly an average rainfall.

Table No. 25. Manchester sewer gaugings.

Table No. 25 gives the dry weather flow of the Manchester sewers at every hour of the day for every day of the week for the dry days of the year 1880. The line upon which the figures rest is the base line for the diagrams above, which shew the fluctuation every day of the week and at every hour of the day.

I have the honour to remain,

Your obedient servant,

BALDWIN LATHAM.

Average dry weather flow 40·69 gallons per head.
Average water supply 30·18 ,, ,, ,,

TABLE NO. 1.—RHYL SEWERAGE GAUGINGS—1900.

Area, 152 acres.
Population, 8,300, not including visitors.

Date.	Rainfall Inches.	Number of days ·01 in. or more fell.	Total flow in sewers. Gallons.	Sewage dry weather flow including leakage. Gallons.	Rainfall flowing off. Gallons.	Water supply Gallons.	Rainfall and leakage. Gallons.
January -	2·63	20	14,107,365	10,973,918	3,133,447	5,945,000	8,162,365
February -	2·68	18	13,526,825	10,376,701	3,150,124	6,385,176	7,141,649
March -	1·02	8	11,399,825	10,304,385	1,095,440	6,439,624	4,960,201
April -	1·25	12	9,767,640	7,819,431	1,948,209	5,668,824	4,098,816
May - -	1·26	11	8,999,130	7,779,250	1,219,880	6,994,592	2,004,538
June - -	1·21	11	9,703,280	8,748,270	955,010	8,180,732	1,522,548
July - -	1·76	9	11,909,130	9,374,305	2,534,825	9,713,664	2,195,466
August -	4·98	17	23,354,510	13,272,456	10,082,054	10,534,462	12,820,048
September -	·71	8	10,422,935	9,976,504	446,431	9,133,410	1,289,525
October -	4·12	22	18,426,940	10,247,585	8,179,355	7,973,944	10,452,996
November -	3·04	17	20,025,560	12,757,147	7,268,413	7,286,400	12,739,160
December -	1·86	15	14,040,380	11,651,582	2,388,798	7,182,824	6,857,556
Totals -	26·52	168	165,683,520	123,281,534	42,401,986	91,438,652	74,244,868

Average dry weather flow 39·27 gallons per head.
Average water supply 31·39 ,, ,,

TABLE NO. 2.—RHYL GAUGINGS.—1901.

Area, 152 acres.
Population, 8,500, not including visitors.

Date.	Rain-fall. Inches.	Number of days ·01 in. or more fell.	Total flow in sewers. Gallons.	Sewage dry weather flow including leakage. Gallons.	Rainfall flowing off. Gallons.	Water supply. Gallons.	Rainfall and leakage. Gallons.
January -	1·23	10	12,502,190	10,280,562	2,221,628	7,447,440	5,054,750
February -	·67	9	11,543,065	9,779,482	1,763,583	6,571,488	4,971,577
March -	1·80	9	14,975,270	11,973,779	3,001,491	7,221,016	7,754,254
April - -	1·04	13	10,900,985	9,022,285	1,878,700	7,294,680	3,606,305
May - -	·69	6	9,363,180	8,658,440	704,740	8,680,992	682,188
June - -	1·40	10	12,019,810	10,187,330	1,832,480	8,845,980	3,173,830
July - -	2·15	13	13,847,345	10,575,712	3,271,633	10,121,159	3,726,186
August -	2·94	13	17,780,220	11,899,296	5,880,924	11,354,928	6,425,292
September -	·72	7	10,708,940	9,688,173	1,020,767	9,097,380	1,611,560
October -	1·58	15	12,365,360	9,822,764	2,542,596	7,553,830	4,811,528
November -	3·52	13	17,752,335	9,415,707	8,336,628	6,502,320	11,250,015
December -	2·72	21	15,403,170	10,521,955	4,881,215	6,694,512	8,708,658
Totals -	20·46	139	159,161,870	121,825,485	37,336,385	97,385,727	61,776,143

TABLE No. 3.—DEAL SEWERAGE-GAUGINGS—1901 to 1903.

Area 100 acres.

Population 10,500 not including visitors.

Date.	Rainfall. Inches.	No. of days ·01 or more fell.	Total flow in sewers. Gallons.	Dry weather flow. Gallons.	Rainfall flowing off. Gallons.	Water supply to district over periods of 3 months.
1901.						
September - -	1·07	9	10,107,109	8,781,946	1,325,163	
October - - -	1·45	13	10,403,552	9,003,816	1,399,736	
November- - -	1·08	11	9,225,317	8,070,679	1,154,638	23,420,350
December - - -	4·63	16	13,491,201	8,380,244	5,110,957	
1902.						
January - - -	·98	9	9,758,153	8,589,001	1,169,152	
February - - -	1·225	11	8,256,223	7,312,198	944,025	21,160,820
March - - -	1·440	11	9,461,339	8,024,279	1,437,060	
April - - -	·45	7	8,450,818	8,086,625	364,193	
May - - -	1·71	21	9,579,265	8,273,822	1,305,443	21,587,350
June- - - -	2·50	16	10,452,956	8,444,765	2,008,191	
July - - -	1·60	13	9,951,000	8,401,960	1,549,040	
August - - -	3·975	22	13,903,205	9,968,847	3,934,358	24,278,700
September - -	·75	9	10,548,877	9,610,955	937,922	
October - - -	1·525	15	10,071,907	8,908,575	1,163,332	
November - -	2·525	14	10,438,482	8,442,732	1,995,750	23,140,000
December - - -	2·545	18	10,372,195	8,205,474	2,166,721	
1903.						
January - - -	2·39	24	10,225,282	8,580,178	1,645,104	
February - - -	1·68	11	9,299,182	7,797,057	1,502,125	22,472,000
Totals - - -	33·525	250	183,996,063	152,883,153	31,112,910	136,059,220

TABLE No. 4.—MANCHESTER SEWER GAUGINGS.

Date 1899.	Total Gaugings. Gallons.	Dry Weather Flow. Gallons.	Volume due to Rainfall. Gallons.	Flow off area. Inches in depth.	Rainfall in Inches.	Percentage of Rain flowing off.
July 10 to 14 - -	167,265,000	142,808,000	24,357,000	·111	·47	23·61
July 18 to 19 - -	69,267,000	58,188,000	11,079,000	·051	·19	26·74
July 22 - . -	40,747,000	25,865,000	14,882,000	·068	·25	27·20
August 16 to 19 -	118,978,000	110,024,000	8,954,000	·041	·18	22·77
September 6 . -	43,956,000	29,083,000	14,873,000	·068	·24	28·41
Sept. 14 to Oct. 5 -	1,044,750,000	605,400,000	439,350,000	2·015	4·85	41·54
November 20 to 21 -	58,932,000	55,631,000	3,301,000	·015	·04	37·50
December 3 to 7 -	208,539,000	121,658,000	86,881,000	·398	·71	56·05
	1,752,434,000	1,148,657,000	603,677,000	2·767	6·93	39·82

Table No. 5—SOUTH NORWOOD SEWAGE. Gaugings on Days of Heavy Rainfall, 1866.

Date. 1866.	Rainfall at Croydon on day. Inches.	Average dry weather flow. Cube feet per minute.	Average flow in sewer during day. Cube feet per minute.	Maximum rate of flow over 1 hour. Cube feet per minute.	Total flow in sewer during the day. Cube feet.	Dry weather flow during the day. Cube feet.	Total flow due to rainfall during day. Cube feet.	Times the maximum flow exceeded mean over 1 hour.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volume of sewage in excess of 3 times mean flow. Cube feet.	Volume of sewage in excess of 4 times mean flow. Cube feet.	Volume of sewage in excess of 5 times mean flow. Cube feet.	Volume of sewage in excess of 6 times mean flow. Cube feet.
January 13 -	1·83	20·37	408·71	580·0	588,542	29,333	559,209	28·47	24	24	24	24	500,544	471,211	441,878	412,546
„ 14 -	·20	20·37	152·21	337·5	219,182	29,333	189,849	16·57	24	24	19	14	131,184	101,851	74,157	54,222
„ 16 -	·33	20·37	145·72	304·0	209,837	29,333	180,504	14·92	24	16	13	11	121,838	97,459	79,794	65,360
„ 19 -	·25	20·37	50·32	98·0	72,461	29,333	43,128	4·81	6	4	—	—	8,744	2,285	—	—
„ 22 -	·27	20·37	94·93	278·0	136,699	29,333	107,366	13·65	15	10	7	5	56,601	41,472	31,382	24,774
„ 31 -	·34	20·37	41·73	100·0	60,091	29,333	30,758	4·91	3	1	—	—	3,400	2,333	—	—
February 2 -	·24	20·37	34·64	68·0	49,882	29,333	20,549	3·34	2	—	—	—	467	—	—	—
July 6 -	·33	14·29	72·61	451·8	104,558	20,578	83,980	31·62	13	9	7	6	53,703	44,177	37,741	32,224
„ 28 -	·14	14·29	20·19	61·6	29,074	20,578	8,496	4·31	1	—	—	—	1,124	—	—	—
August 1 -	·20	14·29	16·33	29·6	23,515	20,578	2,937	2·07	—	—	—	—	—	—	—	—
„ 6 -	·30	14·29	21·83	28·8	31,435	20,578	10,857	2·01	—	—	—	—	—	—	—	—
„ 7 -	·15	14·29	19·52	37·5	28,109	20,578	7,531	2·62	—	—	—	—	—	—	—	—
„ 8 -	·14	14·29	23·63	71·1	34,027	20,578	13,449	4·98	2	2	—	—	2,674	959	—	—
„ 11 -	·24	14·29	20·96	42·0	30,182	20,578	9,604	2·94	2	—	—	—	1,174	—	—	—
Totals -	4·96	242·62	1123·33	2487·9	1,617,594	349,377	1,268,217	137·22	116	90	70	60	881,453	761,747	664,952	589,126
Means 14 days	·35	17·33	80·24	177.71	115,542	24,956	90,587	9·80	8·29	6·43	5·00	4·29	62,961 54·49 °/。 of total flow.	54,411 47·09 °/。 of total flow.	47,497 41·11 °/。 of total flow.	42,080 36·42 °/。 of total flow.

TABLE No. 6.—GAUGINGS AT FRIERN BARNET SEWAGE WORKS. WET DAYS.—YEAR, 1887.

Date. 1887	Rainfall on day.		Average dry weather flow.	Average flow in sewer on day.	Maximum flow over one hour.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes the maximum flow exceeded mean over 1 hour.	Total flow in sewer during the day.	Total dry weather flow during day.	Total flow due to Rainfall during day.	Volume of sewage in excess of 3 times.	Volume of sewage in excess of 4 times.	Volumes of sewage in excess of 5 times.	Volumes of sewage in excess of 6 times.
	Whet-stone.	Sewage Works.	Cube feet per minute.	Cube feet per minute.	Cube feet per minute.						Cube feet.	Cube feet.	Cube feet.	Cube feet.	Cube feet.	Cube feet.	Cube feet.
August 16 - -	·54	·65	8·48	14·52	95·0	5	4	3	3	11·22	20,909	12,211	8,698	9,588	7,459	5,655	4,138
" 17 - -	·09	·10	8·48	11·46	36·0	1	1	—	—	4·25	16,502	12,211	4,291	634	125	—	—
" 20 - -	·03	·20	8·48	10·74	27·4	1	—	—	—	3·23	15,466	12,211	3,255	118	—	—	—
" 26 - -	·015	·03	8·48	11·51	56·7	3	2	2	1	6·69	16,574	12,211	4,363	3,485	2,350	1,332	349
" 28 - -	·05	·33	8·48	11·22	44·2	2	1	1	—	5·21	16,157	12,211	3,946	1,243	617	108	—
" 29 - -	·18	·09	8·48	15·26	50·3	1	1	1	—	5·93	21,974	12,211	9,763	1,492	983	474	—
" 30 - -	·66	·56	8·48	32·42	92·4	10	7	6	5	10·90	46,685	12,211	34,474	16,620	12,386	9,245	6,426
" 31 - -	·11	·73	8·48	40·61	250·6	8	5	4	4	29·55	58,478	12,211	46,267	32,554	28,866	26,568	24,533
September 1 -	·41	·37	8·48	29·27	116·5	12	5	3	2	13·74	42,149	12,211	29,938	11,909	8,232	6,179	4,688
" 2 -	·08	·07	8·48	15·04	35·4	3	1	—	—	4·17	21,658	12,211	9,447	1,150	89	—	—
" 3 -	·32	·41	8·48	17·58	50·3	6	3	2	—	5·93	25,315	12,211	13,104	4,583	2,228	948	—
" 4 -	·05	·07	8·48	14·08	27·4	1	—	—	—	3·23	20,275	12,211	8,064	118	—	—	—
" 6 -	·37	·30	8·48	17·28	108·3	3	3	1	1	12·77	24,883	12,211	12,672	6,341	4,815	3,954	3,445
" 7 -	·07	·07	8·48	21·92	56·7	9	4	1	1	6·69	31,565	12,211	19,354	5,238	1,982	858	349
" 16 -	·55	·45	8·48	17·83	50·3	4	4	3	—	5·93	25,675	12,211	13,464	5,246	3,211	1,422	—
" 17 -	·25	·30	8·48	29·48	100·2	9	8	7	6	11·82	42,451	12,211	30,240	17,431	13,090	9,265	5,738
" 26 -	·21	·17	8·48	17·43	44·2	3	3	1	—	5·21	25,099	12,211	12,888	2,248	722	108	—
" 30 -	·11	·17	8·48	13·42	33·4	3	—	—	—	3·93	19,325	12,211	7,114	1,175	—	—	—
October 10 - -	·355	·275	8·48	17·12	56·7	5	3	2	1	6·69	24,653	12,211	12,442	4,506	2,403	1,296	349
Totals - -	4·450	5·345	161·12	358·19	1332·0	89	55	37	24	157·09	515,793	232,009	283,784	125,679	89,558	67,412	50,015
Averages 19 days	·234	·281	8·48	18·85	70·11	4·68	2·89	1·95	1·26	8·27	27,147	12,211	14,936	6,615	4,714	3,548	2,632
														24·37% of total flow.	17·36% of total flow.	13·07% of total flow.	9·7 % of total flow.

Table No. 7.—Gauging of Croydon Outfall Sewer.—Year 1880.

1880.	Rain-fall. depth. Inches.	Number of days when ·01 or more rain fell.	Number of days when the sewer affected by rainfall.	Depth of rainfall flowing off by sewers. Inches.	Average flow in sewer. Cube feet per minute.	Flow in sewer due to leakage. Cube feet per minute.	Dry weather flow in sewer due to water supply. Cube feet per minute.	Flow in sewer due to Rainfall. Cube feet per minute.	Number of days on which the flow in the sewer exceeded 1½ times the mean flow.	Number of days on which the flow in the sewer exceeded twice the mean flow.	Number of days on which the flow in the sewer exceeded 3 times the mean flow.	Number of days on which the flow in the sewer exceeded 4 times the mean flow.	Number of days on which the flow in the sewer exceeded 5 times the mean flow.	Number of days on which the flow in the sewer exceeded 6 times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow in the month.
January - -	·405	5	4	·120	658·9	417·2	238·6	3·1	1	—	—	—	—	—	1·96	1·30
February -	2·750	18	17	1·456	528·1	256·0	231·9	40·2	11	8	3	1	1	—	5·23	2·13
March - -	·640	5	4	·360	544·8	310·7	224·8	9·3	2	1	—	—	—	—	2·45	1·60
April - -	1·885	13	12	·480	526·2	288·4	225·0	12·8	5	5	2	1	1	—	5·49	2·03
May - -	·370	5	5	·105	495·2	269·1	223·4	2·7	2	—	—	—	—	—	1·78	1·31
June - -	3·560	19	19	1·053	471·6	224·8	218·7	28·1	10	5	5	3	2	1	6.65	2·39
July - -	2·985	21	15	·766	429·0	188·2	221·0	19·8	10	6	3	—	—	—	3·84	2·03
August - -	·445	6	4	·124	369·3	147·3	218·8	3·2	1	1	—	—	—	—	2·06	1·51
September -	4·645	15	11	1·693	428·8	166·6	217·0	45·2	9	6	6	6	6	3	6·17	3·82
October - -	7·500	20	19	4·243	596·4	281·2	205·6	109·6	15	14	10	6	4	4	8·97	3·67
November -	2·325	12	10	·922	614·7	376·5	213·6	24·6	9	6	2	1	—	—	4·09	2·33
December -	3·055	17	16	1·932	731·0	485·3	195·8	49·9	12	9	4	4	2	1	6·52	2·69
Totals -	30·565	156	136	13·254	6394·0	3411·3	2634·2	348·5	87	61	35	22	16	9	55·21	26·81
Averages -	—	—	—	—	532·83	284·27	219·52	29·04	—	—	—	—	—	—	4·60	2·23

TABLE No. 8.—GAUGING OF CROYDON OUTFALL SEWER.—YEAR, 1881.

1881.	Rainfall depth. Inches.	Number of days when ·01 or more rain fell.	Number of days when the sewer affected by rainfall.	Depth of rainfall flowing off by sewers. Inches.	Total flow in sewer. Cube feet per minute.	Flow in sewer due to leakage. Cube feet per minute.	Dry weather flow in sewer due to water supply. Cube feet per minute.	Flow in sewer due to rainfall. Cube feet per minute.	Number of days on which the flow in the sewer exceeded 1½ times the mean flow.	Number of days on which the flow in the sewer exceeded twice the mean flow.	Number of days on which the flow in the sewer exceeded 3 times the mean flow.	Number of days on which the flow in the sewer exceeded 4 times the mean flow.	Number of days on which the flow in the sewer exceeded 5 times the mean flow.	Number of days on which the flow in the sewer exceeded 6 times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow in the month.
January - -	1·130	10	7	·401	914·6	666·4	237·1	11·1	4	1	—	—	—	—	2·85	1·67
February - -	3·050	16	12	·968	1089·6	848·4	211·6	29·6	10	8	3	1	1	—	5·85	2·58
March - -	1·550	12	11	·423	1235·3	1016·3	207·5	11·5	5	2	1	1	1	—	5·14	1·85
April - -	·495	7	6	·152	1099·0	876 1	218·4	4·5	3	1	—	—	—	—	2·11	1·52
May - -	·920	11	10	·296	858·1	627·3	223·0	7·8	4	3	—	—	—	—	2·52	1·67
June - -	1·720	10	6	·464	663·1	414·4	235·1	13·6	5	4	2	1	—	—	4·50	2·55
July - -	1·785	16	10	·450	552·7	295·8	243·8	13·1	7	4	3	2	2	1	6·23	2·60
August - -	4·015	20	12	1·413	516·4	264·0	215·9	37·4	9	9	5	4	2	2	7·10	3·49
September -	2·065	18	12	·762	472·0	247·6	208·4	16·0	9	5	4	3	2	—	5·23	2·63
October - -	2·455	15	9	·843	403·0	171·0	209·5	22·5	7	6	4	2	1	1	7·96	3·29
November -	3·615	18	12	1·599	432·0	194·2	193·6	44·2	10	9	5	4	3	2	6·92	3·47
December -	2·865	18	14	1·507	555·5	316·5	198·2	40·8	13	10	7	4	2	2	10·76	3·81
Totals -	25·665	171	121	9.278	8791·3	5938·0	2601·2	252·1	86	62	34	22	14	8	67·17	31·13
Averages -	—	—	—	—	732·61	494·83	216·77	21·01	—	—	—	—	—	—	5·60	2·59

TABLE No. 9.—GAUGING OF CROYDON OUTFALL SEWER.—YEAR, 1882.

1882.	Rainfall depth. Inches.	Number of days when ·01 or more rain fell.	Number of days when the sewer was affected by rainfall.	Depth of rainfall flowing off by sewers. Inches.	Total flow in sewer. Cube feet per minute.	Flow in sewer due to leakage. Cube feet per minute.	Dry weather flow in sewer due to water supply. Cube feet per minute.	Flow in sewer due to rainfall. Cube feet per minute.	Number of days in which the flow in the sewer exceeded 1½ times the mean flow.	Number of days on which the flow in the sewer exceeded twice the mean flow.	Number of days on which the flow in the sewer exceeded 3 times the mean flow.	Number of days on which the flow in the sewer exceeded 4 times the mean flow.	Number of days on which the flow in the sewer exceeded 5 times the mean flow.	Number of days on which the flow in the sewer exceeded 6 times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow in the month.
January - -	1·235	8	6	·480	607·7	400·8	193·7	13·2	5	4	4	2	–	–	4·50	3·13
February - -	1·750	8	6	.657	647·3	439·8	187·5	20·0	5	4	3	2	2	1	6·21	3·36
March - -	·875	9	6	·193	680·9	470·2	205·4	5·3	4	2	–	–	–	–	2·96	1·81
April - -	2·970	16	13	1·021	659·0	419·7	210·3	29·0	9	7	5	3	–	–	5·01	2·70
May - -	·895	8	7	·360	613·6	377·7	226·0	9·9	5	4	2	–	–	–	3·25	2·10
June - -	2·440	20	16	·775	524·8	279·6	223·2	22·0	11	6	4	1	1	–	5·30	2·29
July - -	2·435	22	15	·597	488·5	247·9	224·2	16·4	7	7	4	1	1	1	5·98	2·19
August - -	1·310	13	10	·327	418·5	181·0	228·5	9·0	7	2	1	–	–	–	3·70	1·89
September -	2·565	11	9	·979	397·1	162·4	206·9	27·8	8	7	5	3	2	–	5·72	3·39
October - -	5·695	21	18	3·005	484·0	200·9	200·6	82·5	16	13	13	9	6	4	11·56	4·49
November -	2·230	19	15	·665	482·2	270·9	192·4	18·9	11	8	3	3	1	1	7·06	2·52
December -	2·090	22	18	·939	516·4	304·4	186·2	25·8	10	3	2	1	–	–	4·47	1·81
Totals -	26·490	177	139	9·998	6520·0	3755·3	2484·9	279·8	98	67	46	25	13	7	65·72	31·68
Averages -	–	–	–	–	543·33	312·94	207·07	23·32	–	–	–	–	–	–	5·48	2·64

TABLE No. 10—GAUGING OF CROYDON OUTFALL SEWER.—YEAR, 1883.

1883.	Rainfall Depth. Inches.	Number of days when ·01 or more rain fell.	Number of days when the sewer affected by rainfall.	Depth of rainfall flowing off by sewers. Inches.	Total flow in sewer. Cube feet per minute	Flow in sewer due leakage. Cube feet per minute.	Dry weather flow in sewer due to water supply. Cube feet per minute.	Flow in sewer due to Rainfall. Cube feet per minute.	Number of days on which the flow in the sewer exceeded 1½ times the mean flow.	Number of days on which the flow in the sewer exceeded twice the mean flow.	Number of days on which the flow in the sewer exceeded 3 times the mean flow.	Number of days on which the flow in the sewer exceeded 4 times the mean flow.	Number of days on which the flow in the sewer exceeded 5 times the mean flow.	Number of days on which the flow in the sewer exceeded 6 times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow in the month.
January -	2·065	20	17	·675	627·7	418·0	190·6	19·1	9	6	6	2	—	—	4·59	2·28
February -	4·415	16	16	1·628	1067·0	818·7	197·3	51·0	12	9	7	5	—	—	4·96	2·82
March - -	1·005	9	9	·184	1308·9	1103·5	200·3	5·2	3	2	—	—	—	—	2·68	1·50
April - -	1·545	8	7	·469	1050·2	835·1	201·4	13·7	6	6	3	1	—	—	4·22	2·69
May - -	1·955	10	10	·318	714·3	499·5	205·8	9·0	8	7	5	1	1	—	5·23	2·87
June - -	·845	11	6	·161	590·6	355·8	230·0	4·7	2	1	1	1	1	—	5·31	1·93
July - -	2·215	16	16	·781	516·8	268·8	225·9	22·1	12	4	2	2	1	1	8·17	2·37
August - -	·625	7	5	·198	430·5	190·9	234·0	5·6	3	1	1	1	—	—	4·13	1·99
September -	3·185	19	15	1·584	412·5	151·1	215·1	46·3	12	9	6	4	1	1	13·31	3·39
October - -	1·925	13	11	·735	386·9	162·6	203·5	20·8	9	8	3	2	1	—	5·06	2·67
November -	3·760	18	16	1·758	387·9	138·9	197·6	51·4	13	11	7	5	4	3	7·40	3·46
December -	·610	12	5	·258	356·4	155·5	193·6	7·3	2	1	1	1	—	—	4·13	1·88
Totals - -	24·150	159	133	8·749	7849·7	5098·4	2495·1	256·2	91	65	42	25	9	5	69·19	29·83
Averages -	—	—	—	—	654·14	424·87	207·92	21·35	—	—	—	—	—	—	5·76	2·49

TABLE NO. 11.—GAUGING OF CROYDON OUTFALL SEWER.—YEAR, 1884.

1884.	Rainfall depth. Inches.	Number of days when ·01 or more rain fell.	Number of days when the sewer affected by rainfall.	Depth of rainfall flowing off by sewers. Inches.	Total flow in sewer. Cube feet per minute.	Flow in sewer due to leakage. Cube feet per minute.	Dry weather flow in sewer due to water supply Cube feet per minute.	Flow in sewer due to rainfall. Cube feet per minute.	Number of days on which the flow in the sewers exceeded 1½ times the mean flow.	Number of days on which the flow in the sewer exceeded twice the mean flow.	Number of days on which the flow in the sewer exceeded 3 times the mean flow.	Number of days on which the flow in the sewer exceeded 4 times the mean flow.	Number of days on which the flow in the sewer exceeded 5 times the mean flow.	Number of days on which the flow in the sewer exceeded 6 times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow in the month.
January - -	2·560	16	15	1·011	377·3	163·9	184·0	29·4	12	8	3	3	3	3	12·11	3·33
February -	1·765	12	12	·936	462·7	243·0	190·6	29·1	8	8	6	3	1	–	5·16	2·75
March - -	1·695	9	9	·650	514·4	311·7	183·8	18·9	7	4	2	2	2	1	6·24	2·76
April - -	1·285	14	11	·562	545·4	338·9	189·6	16·9	6	4	3	2	1	–	5·96	2·31
May - -	·635	9	6	·464	514·9	287·8	213·6	13·5	4	2	1	1	–	–	4·44	2·18
June - -	1·675	9	7	·649	470·3	230·8	220·0	19·5	6	4	3	2	2	1	9·21	3·58
July - -	1·610	15	14	·897	397·3	139·7	231·5	26·1	9	6	2	1	1	1	6·25	2·22
August - -	1·105	8	6	·306	338·7	95·0	234·8	8·9	5	3	2	1	1	1	6·42	2·91
September -	2·370	13	10	·695	338·1	111·6	205·6	20·9	7	6	4	4	2	1	7·54	3·17
October - -	1·230	11	9	·464	286·3	81·1	191·7	13·5	6	3	2	1	–	–	4·07	2·11
November -	1·535	12	11	·602	263·5	61·0	184·4	18·1	7	7	3	1	1	1	7·16	2·59
December -	2·305	17	15	·866	286·7	80·8	180·7	25·2	13	11	6	3	1	–	5·20	2·83
Totals - -	19·770	145	125	8·102	4795·6	2145·3	2410·3	240·0	90	66	37	24	15	9	79·76	32·74
Averages -	—	—	—	—	399·63	178·77	200·86	20·00	—	—	—	—	—	—	6·65	2·73

TABLE NO. 12.—GAUGING OF CROYDON OUTFALL SEWER.—YEAR, 1885.

1885.	Rainfall depth. Inches.	Number of days when ·01 or more rain fell.	Number of days when the sewer affected by rainfall.	Depth of rainfall flowing off by sewers. Inches.	Total flow in sewer. Cube feet per minute.	Flow in sewer due to leakage. Cube feet per minute.	Dry weather flow in sewer due to water supply. Cube feet per minute.	Flow in sewer due to rainfall. Cube feet per minute.	Number of days in which the flow in the sewer exceeded 1½ times the mean flow.	Number of days in which the flow in the sewer exceeded twice the mean flow.	Number of days in which the flow in the sewer exceeded 3 times the mean flow.	Number of days in which the flow in the sewer exceeded 4 times the mean flow.	Number of days in which the flow in the sewer exceeded 5 times the mean flow	Number of days in which the flow in the sewer exceeded 6 times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow in the month.
January - -	2·035	13	12	·742	268·7	56·6	189·9	22·2	8	7	4	3	2	2	7·03	2·98
February -	2·770	19	17	1·009	323·4	106·2	183·8	33·4	13	8	6	3	2	1	6·08	2·60
March - -	1·690	8	8	·686	354·0	147·9	185·6	20·5	5	5	4	3	2	—	5·17	3·02
April - -	2·010	11	9	·760	409·3	190·8	195·2	23·3	8	6	4	3	1	1	6·57	3·19
May - -	3·140	17	15	1·274	448·8	223·2	187.5	38·1	13	12	7	3	2	1	6·27	3·06
June - -	1·685	10	10	·793	429·0	196·4	208·1	24·5	8	4	2	2	2	2	9·38	2·97
July - -	·255	2	1	·087	351·5	108·0	240·9	2·6	1	1	1	—	—	—	3·36	3·36
August - -	1·405	11	10	·569	327·5	93·9	216·6	17·0	8	5	3	2	1	—	5·22	2·67
September -	4·230	21	18	1·787	359·1	112·4	191·5	55·2	14	12	8	4	3	3	7·60	3·19
October -	3·455	19	19	1·455	340·8	119·6	177·7	43·5	13	11	9	7	5	3	7·18	3·19
November -	2·765	18	15	1·195	350·2	136·1	177·2	36·9	12	11	7	5	3	1	6·32	3·28
December -	1·175	14	9	·519	360·9	169·0	176·4	15·5	8	7	3	1	—	—	4·89	2·63
Totals - -	26·615	163	143	10·876	4323·2	1660·1	2330·4	332·7	111	89	58	36	23	14	75·07	36·14
Averages	—	—	—	—	360·27	138·34	194·20	27·73	—	—	—	—	—	—	6·26	3·01

TABLE No. 13.—GAUGING OF CROYDON OUTFALL SEWER.—YEAR, 1886.

1886.	Rainfall depth. Inches.	Number of days when ·01 or more fell.	Number of days when the sewer affected by rainfall.	Depth of Rainfall flowing off by sewers. Inches.	Total flow in sewer. Cube feet per minute.	Flow in sewer due to leakage. Cube feet per minute.	Dry weather flow in sewer due to water supply. Cube feet per minute.	Flow in sewer due to rainfall. Cube feet per minute.	Number of days in which the flow in the sewer exceeded 1½ times the mean flow.	Number of days in which the flow in the sewer exceeded twice the mean flow.	Number of days in which the flow in the sewer exceeded 3 times the mean flow.	Number of days in which the flow in the sewer exceeded 4 times the mean flow.	Number of days in which the flow in the sewer exceeded 5 times the mean flow.	Number of days in which the flow in the sewer exceeded 6 times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow in the month.
January - -	3·300	22	22	1·020	516·7	306·5	178·9	31·3	16	13	3	1	—	—	4·40	2·26
February - -	·455	9	4	·221	555·2	375·5	172·2	7·5	3	3	2	2	2	—	5·26	3·40
March - -	1·305	13	11	·424	551·4	365·2	173·2	13·0	8	6	1	—	—	—	3·19	2·08
April - -	1·470	15	14	·303	557·0	366·8	180·6	9·6	10	6	4	1	—	—	4·08	2·20
May - -	4·350	17	17	1·909	624·2	386·8	178·8	58·6	15	10	7	4	4	4	13·78	4·51
June - -	·755	7	5	·400	514·4	305·6	196·1	12·7	3	3	2	2	1	1	13·37	4·76
July - -	2·425	13	12	·805	465·5	215·7	225·1	24·7	10	7	5	2	1	1	6·38	2·85
August - -	1·015	15	12	·573	373·2	147·0	208·6	17·6	6	4	1	—	—	—	3·81	1·85
September -	1·845	11	10	·602	312·2	75·7	217·4	19·1	7	6	3	2	1	1	12·41	3·25
October - -	2·290	21	11	·783	274·6	57·3	193·3	24·0	9	9	5	3	3	—	5·93	3·32
November -	3·335	18	15	1·393	285·9	55·7	186·0	44·2	12	10	9	6	5	4	8·02	3·99
December -	4·410	19	18	1·453	318·1	76·8	196·7	44·6	15	11	5	4	3	3	10·18	3·39
Totals - -	26·955	180	151	9·886	5348·4	2734·6	2306·9	306·9	114	88	47	27	20	14	90·81	37·86
Averages -	—	—	—	—	445·70	227·88	192·24	25·58	—	—	—	—	—	—	7·57	3·16

TABLE NO. 14.—SUMMARY GAUGINGS OF CROYDON OUTFALL SEWER.—FROM 1880 TO 1886.

Year.	Rainfall. Depth in inches.	Number of days when ·01 or more rain fell.	Number of days when sewer affected by Rainfall.	Depth of Rainfall flowing off by sewers. Inches.	Total flow in sewer. Cube feet per minute.	Flow in sewer due to leakage. Cube ft. per minute.	Dry weather flow in sewer due to water supply. Cube feet per minute.	Flow in sewer due to Rainfall. Cube ft. per minute.	Number of days on which flow in the sewer exceeded 1½ times the mean flow.	Number of days on which flow in the sewer exceeded twice the mean flow.	Number of days on which flow in the sewer exceeded three times the mean flow.	Number of days on which flow in the sewer exceeded four times the mean flow.	Number of days on which flow in the sewer exceeded five times the mean flow.	Number of days on which flow in the sewer exceeded six times the mean flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Average number of volumes the maximum flow exceeded the mean flow.	Total flow in sewer during the year. Cube feet.	Flow in sewer due to leakage. Cube feet.	Flow in sewer due to water supply. Cube feet.	Flow in sewer due to Rainfall Cube feet.	Percentage of Rain flowing off by the sewers.
1880 - -	30·565	156	136	13·254	532·83	284·27	219·52	29·04	87	61	35	22	16	9	4·60	2·23	280,822,723	149,821,660	115,695,821	15,305,242	43·36
1881 - -	25·665	171	121	9·271	732·61	494·83	216·77	21·01	86	62	34	22	14	8	5·60	2·59	385,059,816	260,082,648	113,934,312	11,042,856	36·12
1882 - -	26·490	177	139	9·998	543·33	312·94	207·07	23·32	98	67	46	25	13	7	5·48	2·64	285,574,248	164,481,264	108,835,992	12,256,992	37·74
1883 - -	24·150	159	133	8·749	654·14	424·87	207·92	21·35	91	65	42	25	9	5	5·76	2·49	343,815,984	223,311,672	109,282,752	11,221,560	36·23
1884 - -	19·770	145	125	8·102	399·63	178·77	200·86	20·00	90	66	37	24	15	9	6·65	2·73	210,620,995	94,218,941	105,861,254	10,540,800	40·98
1885 - -	26·615	163	143	10·876	360·27	138·34	194·20	27·73	111	89	58	36	23	14	6·26	3·01	189,357,912	72,711,504	102,071,520	14,574,888	40·86
1886 - -	26·955	180	151	9·886	445·70	227·88	192·24	25·58	114	88	47	27	20	14	7·57	3·16	234,259,920	119,773,728	101,041,344	13,444,848	36·68
Totals - -	180·210	1,151	948	70·136	3,668·51	2,061·90	1,438·58	168·03	677	498	299	181	110	66	41·92	18·85	1,929,511,598	1,084,401,417	756,722,995	88,387,186	271·97
Averages -	25·744	164	135	10·019	524·07	294·56	205·51	24·00	97	71	43	26	16	9	5·99	2·69	275,644,514	154,914,488	108,103,285	12,626,741	38·92

TABLE No. 15.—CROYDON OUTFALL SEWER. GAUGINGS ON DAYS OF HEAVY RAINFALL.—1880.

Date. 1880.	Rainfall on day. Inches.	Average flow in sewer excluding leakage. Cube feet per minute.	Average flow due to leakage. Cube feet per minute.	Average dry weather flow or volume of water supply. Cube feet per minute.	Maximum flow in sewer exclusive of leakage over one hour. Cube feet per minute.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Total flow in sewer over 24 hours exclusive of leakage. Cube feet.	Total flow in sewer in excess of three times the dry weather flow. Cube feet.	Total flow in sewer in excess of 4 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 5 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 6 times the dry weather flow. Cube feet.	Discharge of sewer at time of maximum flow with leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow. Rainfall only. Cube feet per acre per minute.
February 16	·540	485·4	230	224·7	1175	3	1	1	Nil.	5·23	698,976	40,302	16,572	3,090	Nil.	4·423	3·697	2·991
April 14	·650	371·3	308	218·6	1202	3	3	2	Nil.	5·49	534,672	79,344	40,009	8,340	Nil.	4·753	3·784	3·096
June 21	·375	356·0	230	221·8	1480		2	2	Nil.	5·63	512,640	83,952	57,336	30,720	8,952	4·659	3·935	3·237
June 22	·295	307·1	235	221·8	1475	1	1	1	1	6·65	442,224	48,576	35,268	21,960	8,652	5·383	4·643	3·945
July 10	·350	300·5	220	217·9	836	1	Nil.	Nil.	Nil.	3·84	432,720	10,938	Nil.	Nil.	Nil.	3·324	2·632	1·946
September 11	1·370	539·7	140	221·8	1370	7	6	4	1	6·17	777,168	194,170	101,747	35,700	2,352	4·753	4·313	3·614
September 12	·445	332·4	140	217·3	1165	3	3	1	Nil.	5·36	478,656	60,017	10,903	4,710	Nil.	4·108	3·667	2·983
September 14	1·270	625·9	140	217·3	1330	11	6	2	1	6·12	901,296	170,049	71,748	25,680	1,572	4·627	4·187	3·503
September 15	·325	347·1	180	217·3	1330	2	2	1	1	6·12	499,824	58,812	32,736	14,640	1,572	4·753	4·187	3·503
September 18	·610	412·9	185	217·3	1275	4	3	2	Nil.	5·87	594,576	100,104	57,803	22,620	Nil.	4·596	4·013	3·329
September 19	·225	308·0	185	212·4	1084	1	1	1	Nil.	5·10	443,520	26,808	14,064	1,320	Nil.	3·995	3·412	2·744
October 6	·710	454·0	170	204·5	1340	6	3	3	1	6·55	653,760	116,219	65,520	28,710	6,780	4·753	4·218	3·574
October 9	2·120	972·7	225	204·5	1835	19	16	11	5	8·97	1,400,688	606,870	383,405	214,949	119,700	6·486	5·776	5·133
October 26	·950	633·4	361	210·2	1544	10	3	2	1	7·34	912,096	140,520	72,936	39,060	16,968	5·997	4·860	4·199
October 28	·430	506·1	384	210·2	1516	4	3	3	3	7·21	728,784	146,136	101,137	63,299	25,463	5·981	4·772	4·110
December 19	·555	369·9	490	188·7	1230	5	4	3	2	6·52	532,656	129,090	82,848	41,958	11,736	5·414	3·872	3·278
December 20	·350	340·2	540	188·7	1066	4	2	1	Nil.	5·66	489,888	55,896	22,524	7,350	Nil.	5·055	3·356	2·762
Totals	11·570	7662·6	4363	3615·0	—	86	59	40	16	103·83	11,034,144	2,067,803	1,166,556	564,106	203,747	83·060	69·324	57·947
Averages 17 days	·681	450·7	256·6	212·6	—	—	—	—	—	—	—	—	—	—	--	4·886	4·078	3·409

TABLE NO. 16.—CROYDON OUTFALL SEWER. GAUGINGS ON DAYS OF HEAVY RAINFALL.—YEAR 1881.

Date, 1881.	Rainfall on day. Inches.	Average flow in sewer excluding leakage. Cube feet per minute.	Average flow due to leakage. Cube feet per minute.	Average dry weather flow or volume of water supply. Cube feet per minute.	Maximum flow in sewer, exclusive of leakage over one hour. Cube feet per minute.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Total flow in sewer over 24 hours exclusive of leakage. Cube feet.	Total flow in sewer in excess of 3 times the dry weather. Cube feet.	Total flow in sewer in excess of 4 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 5 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 6 times the dry weather flow. Cube feet.	Discharge of sewer at time of maximum flow with leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow. Rainfall only. Cube feet per acre per minute.
February 7 - -	·530	369·6	780	229·6	1,343	1	1	1	Nil.	5·85	532,224	39,252	25,476	11,700	Nil.	6·470	4·093	3·393
March 5 - -	·510	309·7	1,026	205·9	1,057	2	2	1	Nil.	5·14	445,968	43,356	18,648	1,650	Nil.	6·348	3·221	2·594
June 17 - -	·530	231·6	416	251·2	935	2	Nil.	Nil,	Nil.	4·50	333,504	19,608	Nil.	Nil.	Nil.	4·712	3·444	2·678
July 6 - - -	·160	329·9	290	245·1	1,525	2	1	1	1	6·23	475,056	49,644	32,676	17,970	3,264	5·534	4·651	3·904
July 31- - -	·365	305·4	260	210·9	1,107	2	2	1	Nil.	5·25	439,776	46,176	20,868	3,150	Nil.	4·166	3·738	2·731
August 12 - -	1·230	571·0	250	208·7	1,385	7	5	4	1	6·73	822,240	175,758	94,980	38,700	7,968	4·983	4·282	3·646
August 21 - -	·405	336·3	275	168·8	1,203	4	2	2	2	7·10	484,272	68,778	59,436	39,180	18,924	4·492	3·654	3·142
September 5- -	·345	262·5	293	216·9	632	Nil.	Nil.	Nil.	Nil.	5·23	378,000	Nil.	Nil.	Nil.	Nil.	4·350	3·456	2·795
September 20 -	·270	292·0	235	200·7	1,005	2	2	2	Nil.	5·01	420,480	48,348	24,264	180	Nil.	3·779	3·063	2·451
October 22 - -	1·100	531·9	163	207·8	1,125	6	5	1	Nil.	4·96	765,936	124,715	54,180	5,160	Nil.	3·639	3·142	2·509
October 23 - -	·015	381·0	165	188·3	1,634	2	2	1	1	7·96	548,640	83,532	60,936	41,550	30,252	5·074	4·571	3·998
November 24 -	·580	406·4	175	198·6	1,345	5	4	4	2	6·77	585,216	147,780	88,944	41,280	10,608	4·632	4·099	3·494
November 25 -	·410	417·1	200	193·1	972	8	6	1	Nil.	5·03	600,624	107,674	25,416	390	Nil.	3·572	2·962	2·374
November 26 -	1·130	592·8	200	196·5	1,398	10	6	3	2	6·92	853,632	204,300	105,779	56,610	22,080	4·870	4·178	3·579
December 6 - -	·555	390·4	263	187·2	1,683	4	3	2	2	8·99	562,176	120,456	83,795	59,880	37,416	5·931	5·129	4·559
December 19- -	·395	420·1	310	191·5	2,060	2	2	1	1	10·76	604,944	101,760	79,380	66,150	54,660	7·223	6·278	5·694
Totals - - -	8·530	6147·7	5,301	3300·8	—	59	43	25	12	102·43	8,852,688	1,381,137	774,778	383,550	185,172	79·775	63·961	53·541
Average 16 days -	·533	384·2	331·3	—	—	—	—	—	—	6·40	—	—	—	—	—	4·986	3·998	3·346

TABLE NO. 17.—CROYDON OUTFALL SEWER. GAUGINGS ON DAYS OF HEAVY RAINFALL.—YEAR, 1882.

Date. 1882.	Rainfall on day. Inches.	Average flow in sewer excluding leakage. Cube feet per minute.	Average flow due to leakage. Cube feet per minute.	Average dry weather flow or volume of water supply. Cube feet per minute.	Maximum flow in sewer exclusive of leakage over one hour. Cube feet per minute.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes of maximum flow exceeded the mean flow over one hour.	Total flow in sewer over 24 hours exclusive of leakage. Cube feet.	Total flow in sewer in excess of 3 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 4 times the dry weather flow. Cube feet.	Total flow, in sewer in excess of 5 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 6 times the dry weather flow. Cube feet.	Discharge of sewer at time of maximum flow with leakage. Cube feet. per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow. Rainfall only. Cube feet per acre per minute.
January 8th -	·370	327·5	403	193·2	870	3	1	Nil.	Nil.	4·50	471,600	37,692	5,832	Nil.	Nil.	3·766	2·574	2·002
February 15th -	·310	241·8	445	187·0	1155	2	1	1	1	6·21	348,192	38,040	24,420	13,200	1,980	4·734	3·417	2·864
February 28th -	·510	362·5	445	166·9	857	5	2	1	Nil.	5·13	522,000	46,890	11,748	1,350	Nil.	3·852	2·536	2·042
March 25th - -	·500	291·4	470	224·6	664	Nil.	Nil.	Nil.	Nil.	2·96	419,616	Nil.	Nil.	Nil.	Nil.	3·355	1·965	1·300
April 25th - -	·775	471·7	400	208·4	1031	6	4	Nil.	Nil.	4·95	679,248	95,386	26,376	Nil.	Nil.	4·334	3·050	2·434
April 29th - -	·400	363·8	405	238·6	1195	3	1	1	Nil.	5·01	523,872	44,435	14,436	120	Nil.	4·734	3·536	2·830
May 5th - -	·225	311·2	445	213·7	641	Nil.	Nil.	Nil.	Nil.	3·00	448,128	Nil.	Nil.	Nil.	Nil.	3·213	1·896	1·264
June 24th - -	·360	325·6	257	230·0	912	1	Nil.	Nil.	Nil.	3·97	468,864	13,320	Nil.	Nil.	Nil	3·459	2·698	2·018
June 26th - -	·280	340·9	256	218·1	1155	2	1	1	Nil.	5·30	490,896	32,004	16,956	3,870	Nil.	4·175	3·417	2·772
July 8th - -	·435	330·4	256	223·2	1334	2	1	1	Nil.	5·98	475,776	51,528	26,472	13,080	Nil.	4·704	3·947	3·286
August 29th -	·165	270·8	203	206·9	767	1	Nil.	Nil.	Nil.	3·70	389,952	8,358	Nil.	Nil.	Nil.	2·870	2·269	1·657
September 14th -	·125	297·3	154	212·2	1214	2	1	1	Nil.	5·72	428,112	40,068	21,912	9,180	Nil.	4·047	3·592	2·964
September 19th -	·650	424·8	162	202·2	975	6	1	Nil.	Nil.	4·82	611,712	50,483	9,972	Nil.	Nil.	3·364	2·885	2·286
September 28th -	·860	431·8	160	211·6	1080	5	3	2	Nil.	5·06	621,792	93,840	36,049	2,640	Nil.	3·639	3·166	2·540
October 2nd - -	·210	298·6	160	200·6	1162	2	2	1	Nil.	5·79	429,984	47,004	22,932	954	Nil.	3·911	3·438	2·844
October 15th -	·750	446·8	173	197·5	1036	9	4	1	Nil.	5·25	643,392	92,948	18,000	2,940	Nil.	3·577	3·065	2·481
October 23rd -	·495	333·2	225	186·0	1605	3	3	1	1	8·63	479,808	109,319	75,839	42,540	29,340	5·414	4·749	4·198
October 24th -	·260	325·1	235	208·9	1255	3	2	1	1	6·01	468,144	63,594	35,448	12,630	96	4·408	3·713	3·095
October 27th -	·950	562·8	255	190·7	2205	6	5	4	3	11·56	810,432	310,403	247,620	201,720	163,165	7·278	6·524	5·960
October 28th -	·545	857·6	266	191·4	2174	9	8	8	8	11·39	1,234,944	601,630	506,292	414,420	322,550	7·219	6·432	5·866
November 7th -	·320	279·3	258	195·9	1482	2	1	1	1	7·06	402,192	54,636	41,904	30,150	18,396	5·148	4·385	3·805
December 30th -	·215	287·2	334	186·7	835	4	3	Nil.	Nil.	4·47	413,568	49,296	11,556	Nil.	Nil.	3·459	2·470	1·918
Totals - -	9·710	8182·1	6367	4494·3	—	76	44	25	15	126·47	11,782,224	1,880,874	1,153,764	748,794	535,527	94·660	75·724	62·426
Averages 22 days	·441	371·9	289·3	204·3	—	—	—	—	—	5·75	—	—	—	—	—	4·303	3·442	2·838

Table No. 18.—CROYDON OUTFALL SEWER. Gaugings on Days of Heavy Rainfall.—Year 1883.

Date. 1883.	Rainfall on day. Inches.	Average flow in sewer excluding leakage. Cube feet per minute.	Average flow due to leakage. Cube feet per minute.	Average dry weather flow or volume of water supply. Cube feet per minute.	Maximum flow in sewer exclusive of leakage over one hour. Cube feet per minute.	Number of hours the flow exceeded 3 times the dry weather flow	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Total flow in sewer over 24 hours exclusive of leakage. Cube feet.	Total flow in sewer in excess of 3 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 4 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 5 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 6 times the dry weather flow. Cube feet.	Discharge of sewer at time of maximum flow with leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow. Rainfall only. Cube feet per acre per minute.
January 15	·305	359·0	415	188·4	906	3	2	Nil.	Nil.	4·59	516,960	43,130	14,112	Nil.	Nil.	3·682	2·489	1·948
February 10	·735	512·1	697	202·4	1,002	7	5	Nil.	Nil.	4·96	737,424	112,942	39,948	Nil.	Nil.	4·884	2·880	2·299
March 19	·415	313·1	1,099	195·3	490	Nil.	Nil.	Nil.	Nil.	2·51	450,864	Nil.	Nil.	Nil.	Nil.	4·568	1·409	·847
April 18	·585	313·5	751	214·1	904	3	1	Nil.	Nil.	4·22	451,440	21,305	2,856	Nil.	Nil.	4·758	2·599	1·983
May 9	·250	189·4	569	183·4	981	1	1	1	Nil.	5·23	272,736	25,848	14,844	3,840	Nil.	4·395	2·760	2·232
June 26	·290	306·5	320	217·1	1,154	1	1	1	Nil.	5·31	441,360	30,162	17,136	4,110	Nil.	4·237	3·317	2·693
July 21	·495	298·4	248	214·7	1,057	1	1	Nil.	Nil.	4·93	429,696	24,774	11,892	Nil.	Nil.	3·751	3·038	2·421
July 23	·435	361·3	245	208·7	1,705	3	2	1	1	8·17	520,272	88,601	54,384	39,690	27,168	5·606	4·901	4·301
August 31	·290	323·6	135	225·2	931	2	2	Nil.	Nil.	4·13	465,984	28,848	1,824	Nil.	Nil.	3·064	2·676	2·029
September 10	·655	467·1	135	220·2	2,931	2	2	2	2	13·31	672,624	171,888	145,468	119,040	92,616	8·814	8·426	7·793
October 15	·505	354·7	172	201·8	1,020	4	3	1	Nil.	5·06	510,768	68,424	28,404	660	Nil.	3·427	2·932	2·352
November 4	·380	323·9	122	192·7	983	4	2	1	Nil.	5·10	466,416	50,796	15,444	1,170	Nil.	3·177	2·826	2·272
November 17	·290	258·4	144	200·4	1,306	2	1	1	1	6·51	372,096	49,656	30,264	18,240	6,216	4·168	3·754	3·178
November 22	·410	368·9	141	203·5	1,297	3	2	1	1	6·38	531,216	59,369	33,780	16,870	4,560	4·134	3·728	3·143
November 23	·410	336·0	142	197·2	1,458	3	2	2	1	7·40	483,840	85,752	55,644	31,980	16,488	4·599	4·191	3·624
December 10	·350	363·6	160	193·3	799	3	1	Nil.	Nil.	4·13	523,584	20,358	1,548	Nil.	Nil.	2·757	2·297	1·741
Totals	6·800	5449·5	5,495	3258·4	18,924	42	28	11	6	91·94	7,847,280	881,853	467,548	235,600	147,048	70·021	54·223	44·856
Averages 16 days	·425	340·6	343·4	203·7	1182·8	—	—	—	—	5·75	—	—	—	—	—	4·376	3·389	2·804

TABLE No. 19.—CROYDON OUTFALL SEWER. GAUGINGS ON DAYS OF HEAVY RAINFALL.—1884.

Date. 1884.	Rainfall on day. Inches.	Average flow in sewer excluding leakage. Cube feet per minute.	Average flow due to leakage. Cube feet per minute.	Average dry weather flow or volume of water supply. Cube feet per minute.	Maximum flow in sewer exclusive of leakage over one hour. Cube feet per minute.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Total flow in sewer over 24 hours exclusive of leakage. Cube feet.	Total flow in sewer in excess of 3 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 4 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 5 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 6 times the dry weather flow. Cube feet.	Discharge of sewer at time of maximum flow with leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow. Rainfall only. Cube feet per acre per minute.
January 23 - -	·295	313·1	171	178·1	1319	1	1	1	1	7·41	450,864	47,142	36,396	25,710	15,024	4·165	3·687	3·189
January 25 - -	·305	245·3	187	182·5	1263	1	1	1	1	6·92	353,232	42,930	31,980	21,030	10,080	4·053	3·531	3·020
January 26 - -	·860	498·9	195	178·6	2162	5	4	3	3	12·11	718,416	246,240	201,444	166,981	134,833	6·589	6·044	5·544
February 11 -	·280	340·6	228	196·4	1013	3	3	1	Nil.	5·16	490,464	63,083	27,733	1,860	Nil.	3·469	2·832	2·283
March 9 - -	·330	324·3	294	151·7	947	3	2	2	2	6·24	466,992	61,303	39,264	21,060	2,856	3·469	2·647	2·223
March 10 - -	·580	352·5	296	194·4	1135	5	3	2	Nil.	5·96	507,600	91,020	47,412	19,440	Nil.	4·000	3·173	2·641
April 6 - -	·465	337·5	325	164·6	982	4	2	1	Nil.	5·96	486,000	50,328	24,612	9,540	Nil.	3·654	2·745	2·285
May 5 - -	·240	241·6	328	183·5	815	1	1	Nil.	Nil.	4·44	347,904	15,870	4,860	Nil.	Nil.	3·195	2·278	1·765
June 5 - -	·705	446·8	262	208·2	1917	3	2	2	2	9·21	643,392	160,092	123,804	98,820	73,836	6·091	5·359	4·777
June 6 - -	·435	401·3	259	195·1	1054	4	2	2	Nil.	5·40	577,872	64,008	29,832	6,420	Nil.	3·670	2·946	2·401
July 27 - -	·370	329·8	152	191·0	1194	2	1	1	1	6·25	474,912	37,920	25,800	14,340	2,880	3·763	3·338	2·804
August 27 - -	·410	332·3	75	203·7	1311	1	1	1	1	6·42	478,368	41,994	29,772	17,550	5,328	3·874	3·665	3·037
September 3 -	·885	501·6	96	202·9	1529	7	6	3	2	7·54	722,304	197,706	115,225	60,930	35,172	4·528	4·260	3·693
September 4 -	·465	415·4	100	199·1	1173	6	5	2	Nil.	5·90	598,176	124,513	57,840	19,860	Nil.	3·558	3·279	2·722
October 9 - -	·520	328·4	87	212·1	698	1	Nil.	Nil.	Nil.	3·29	472,896	3,702	Nil.	Nil.	Nil	2·194	1·951	1·358
November 2 -	·335	291·6	51	177·2	1268	2	1	1	1	7·16	419,904	46,608	33,552	22,920	12,288	3·687	3·545	3·049
December 5 -	·355	378·8	76	183·3	954	6	5	1	Nil·	5·20	545,472	93,514	30,840	2,250	Nil.	2·879	2·667	2·216
Totals -	7·835	6079·7	3182	3198·4	—	55	40	24	14	110·57	8,754,768	1,387,973	860,366	508,711	292,297	66·838	57·947	49·007
Averages 17 days-	·461	357·6	187·2	188·1	—	—	—	—	—	6·50	—	—	—	—	—	3·932	3·409	2·883

TABLE No. 20.—CROYDON OUTFALL SEWER. GAUGINGS ON DAYS OF HEAVY RAINFALL.—YEAR, 1885.

Date. 1885.	Rainfall on Day. Inches.	Average flow in sewer excluding Leakage. Cube feet per minute.	Average flow due to Leakage. Cube feet per minute.	Average dry weather flow or volume of water supply. Cube feet per minute.	Maximum flow in sewer exclusive of leakage over one hour. Cube feet per minute.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Total flow in sewer over 24 hours exclusive of Leakage. Cube feet.	Total flow in sewer in excess of three times the dry weather flow. Cube feet.	Total flow in sewer in excess of 4 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 5 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 6 times the dry weather flow. Cube feet.	Discharge of sewer at time of maximum flow with leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow. Rainfall only. Cube feet per acre per minute.
January 10	·375	329·0	51	191·3	1,254	3	2	1	1	6·56	473,760	60,259	35,436	17,850	6,372	3·550	3·411	2·891
January 31	·360	332·9	58	192·5	1,353	4	2	1	1	7·03	479,376	69,240	37,440	23,430	11,880	3·838	3·680	3·157
February 8	·355	334·7	90	179·5	1,116	4	3	1	1	6·08	481,968	75,840	36,599	13,110	2,340	3·210	2·965	2·477
February 16	·485	390·3	120	185·5	1,086	6	5	1	Nil	5·86	562,032	103,680	47,160	9,510	Nil	3·281	2·954	2·450
March 3	·435	354·7	129	183·9	950	4	2	1	Nil	5·17	510,768	55,452	16,008	1,830	Nil	2·935	2·584	2·084
March 21	·895	245·8	165	187·7	681	2	Nil	Nil	Nil	3·63	353,952	13,848	Nil	Nil	Nil	2·301	1·853	1·342
March 22	·010	341·8	171	183·1	924	4	3	1	Nil	5·05	492,192	61,788	23,927	510	Nil	2·979	2·514	2·015
April 28	·445	352·6	205	225·2	1,480	3	2	1	1	6·57	507,744	69,133	40,284	21,240	7,728	4·584	4·026	3·413
May 6	·365	389·9	235	191·8	1,022	5	4	2	Nil	5·33	561,456	94,320	43,632	3,960	Nil	3·419	2·780	2·258
May 21	·515	325·7	230	176·4	1,105	2	1	1	1	6·27	469,008	38,676	23,964	13,380	2,796	3·632	3·006	2·526
June 7	·375	318·5	180	191·1	1,295	2	2	1	1	6·78	458,640	65,244	42,312	20,370	8,904	4·012	3·528	3·003
June 8	·760	555·4	180	167·4	1,570	8	6	6	4	9·38	799,776	246,144	177,444	117,180	63,924	4·760	4·271	3·823
August 27	·060	277·3	103	196·1	1,024	1	1	1	Nil	5·22	399,312	26,142	14,376	2,610	Nil	3·066	2·786	2·252
September 7	·765	507·3	123	180·3	1,194	11	5	5	2	6·62	730,512	193,684	89,820	35,730	7,824	3·583	3·248	2·758
September 8	·255	258·0	125	185·5	1,063	2	2	2	Nil	5·73	371,520	53,280	31,020	8,760	Nil	3·232	2·892	2·387
September 10	1·120	624·1	126	196·7	1,494	10	8	6	5	7·60	898,704	316,740	206,318	118,019	56,400	4·409	4·067	3·532
October 6	·320	292·3	125	184·4	936	2	1	1	Nil	5·08	420,912	23,016	11,904	840	Nil	2·886	2·546	2·045
October 23	·970	530·1	104	174·5	1,089	11	5	1	1	6·24	763,344	147,332	45,240	12,990	2,520	3·248	2·962	2·488
October 24	·020	263·8	107	193·7	1,041	1	1	1	Nil	5·38	379,872	27,594	15,972	4,350	Nil	3·123	2·832	2·305
October 30	·400	336·8	123	165·8	1,191	3	3	2	2	7·18	484,992	87,588	57,744	35,160	15,264	3·574	3·240	2·789
October 31	·250	324·6	126	165·7	1,050	3	3	1	1	6·33	467,424	45,463	24,144	13,290	3,348	3·199	2·856	2·406
November 24	·395	357·7	134	180·0	1,006	5	2	2	Nil	5·59	515,088	71,520	32,940	8,280	Nil	3·101	2·737	2·247
November 26	·560	403·8	154	177·1	1,120	4	4	3	2	6·32	581,472	110,268	67,764	32,729	5,448	3·466	3·047	2·565
November 30	·230	270·4	194	178·2	973	3	2	1	Nil	5·46	389,376	46,152	22,524	4,920	Nil	3·175	2·647	2·162
December 28	·280	295·0	149	171·3	837	3	2	Nil	Nil	4·89	424,800	40,459	1,762	Nil	Nil	2·682	2·277	1·811
Totals	11·000	9012·5	3,507	4,604·7	—	106	71	43	23	151·35	12,978,000	2,142,862	1,145,734	520,048	194,748	85·242	75·709	63·186
Average 25 days	·440	360·5	140·3	184·2	—	—	—	—	—	6·05	—	—	—	—	—	3·410	3·028	2·527

TABLE No. 21.—CROYDON OUTFALL SEWER. GAUGINGS ON DAYS OF HEAVY RAINFALL.—YEAR, 1886.

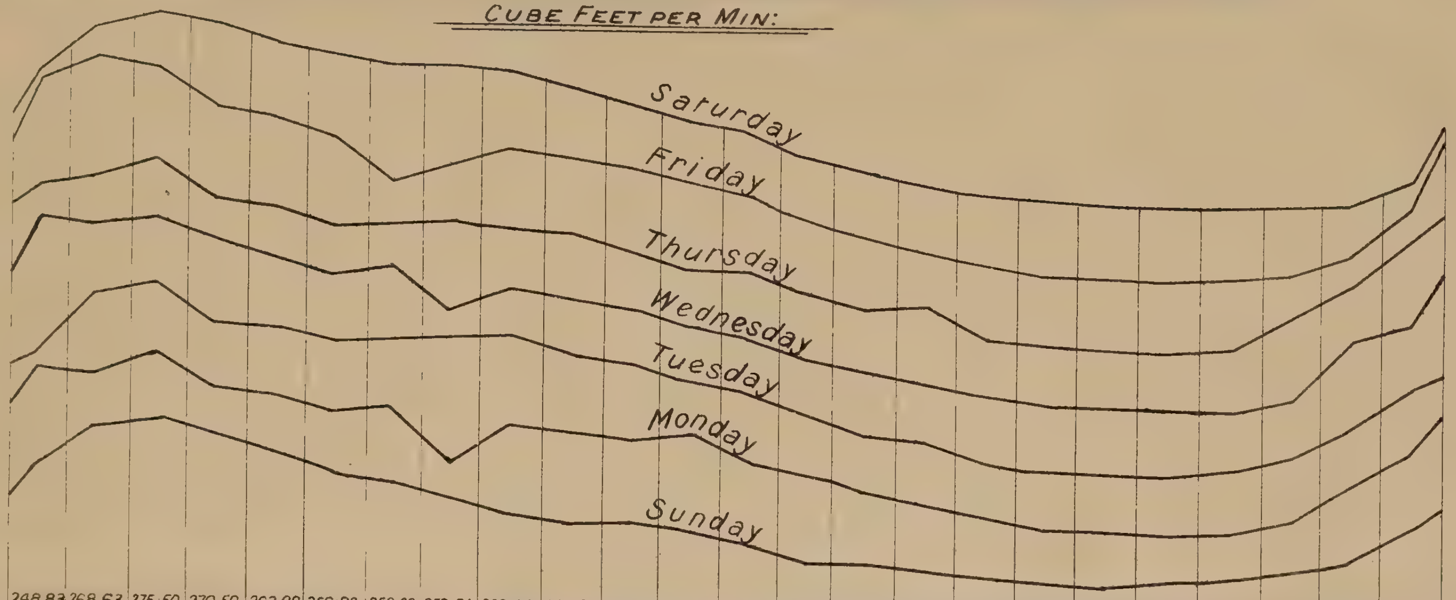
Date. 1886.	Rainfall on day. Inches.	Average flow in sewer excluding leakage. Cube feet per minute.	Average flow due to leakage. Cube eet per minute.	Average dry weather flow or volume of water supply. Cube feet per minute.	Maximum flow in sewer exclusive of leakage over one hour. Cube feet per minute.	Number of hours the flow exceeded 3 times the dry weather flow.	Number of hours the flow exceeded 4 times the dry weather flow.	Number of hours the flow exceeded 5 times the dry weather flow.	Number of hours the flow exceeded 6 times the dry weather flow.	Volumes the maximum flow exceeded the mean flow over one hour.	Total flow in sewer over 24 hours exclusive of leakage. Cube feet.	Total flow in sewer in excess of 3 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 4 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 5 times the dry weather flow. Cube feet.	Total flow in sewer in excess of 6 times the dry weather flow. Cube feet.	Discharge of sewer at time of maximum flow with leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow. Rainfall only. Cube feet per acre per minute
January 3 - -	·170	226·3	181	165·5	729	1	1	Nil	Nil	4·40	325,872	13,950	4,020	Nil	Nil	2·411	1·931	1·493
January 17 - -	·145	239·3	361	175·3	636	2	Nil	Nil	Nil	3·63	344,592	8,292	Nil	Nil	Nil	2·641	1·685	1·221
February 2 - -	·195	250·4	363	173·7	895	1	1	1	Nil	5·15	360,576	22,434	12,012	1,590	Nil	3·333	2·371	1·911
February 3 - -	·140	237·2	363	170·0	895	2	2	1	Nil	5·26	341,568	37,500	17,100	2,700	Nil	3·333	2·371	1·921
March 28 - -	·185	212·2	366	160·9	513	1	Nil	Nil	Nil	3·10	305,568	1,818	Nil	Nil	Nil	2·329	1·359	·933
April 10 - -	·235	230·7	361	175·2	714	1	1	Nil	Nil	4·08	332,208	11,304	792	Nil	Nil	2·848	1·892	1·427
April 28 - -	·390	259·8	386	197·7	743	2	Nil	Nil	Nil	3·76	374,112	14,208	Nil	Nil	Nil	2·991	1·968	1·447
May 12 - -	1·250	572·5	365	165·9	2,285	6	6	5	4	13·78	824,400	374,926	315,202	257,910	217,704	7·020	6·053	5·614
May 21 - -	·405	380·4	420	179·6	2,303	3	3	3	2	12·82	547,776	181,057	148,729	116,401	93,948	7·214	6·101	5·625
May 22 - -	·415	315·5	420	173·9	1,847	3	3	1	1	10·62	454,320	111,353	80,051	58,650	48,216	6·006	4·893	4·432
May 24 - -	1·210	581·0	414	156·5	1,446	12	10	7	5	9·24	836,640	309,182	206,220	125,609	61,980	4·927	3·831	3·416
June 10 - -	·355	287·7	305	104·9	1,402	5	4	2	1	13·37	414,288	97,530	69,996	52,860	46,356	4·522	3·714	3·436
July 25 - -	·770	426·2	215	184·2	1,175	5	4	3	1	6·38	613,728	114,300	63,828	26,820	4,188	3·682	3·113	2·625
August 9 - -	·320	291·7	186	212·6	810	3	Nil	Nil	Nil	3·81	420,048	17,136	Nil	Nil	Nil	2·639	2·146	1·583
September 10 -	·645	431·1	96	190·6	2,365	5	4	3	2	12·41	620,784	192,240	137,844	98,820	74,688	6·520	6·265	5·760
October 7 - -	·185	315·9	55	193·2	1,091	1	1	1	Nil	5·65	454,896	30,684	19,092	7,500	Nil	3·036	2·890	2·378
October 12 - -	·695	417·2	55	189·9	1,126	5	4	2	Nil	5·93	600,768	99,810	53,796	15,720	Nil	3·129	2·983	2·480
October 14 - -	·245	286·8	55	190·5	1,046	2	1	1	Nil	5·49	412,992	30,060	17,040	5,610	Nil	2·917	2·771	2·266
November 5 -	·635	377·8	48	179·8	1,442	4	3	2	1	8·02	544,032	109,044	65,892	42,000	21,792	3·947	3·820	3·344
November 10 -	·405	290·5	52	190·2	1,192	2	1	1	1	6·27	418,320	45,768	25,872	14,460	3,048	3·296	3·158	2·654
November 11 -	·625	495·3	53	185·5	1,383	8	5	4	2	7·46	713,232	181,862	103,260	50,940	18,420	3·788	3·648	3·156
November 16 -	·265	297·3	54	189·8	1,074	2	2	1	Nil	5·66	428,112	50,712	27,936	7,500	Nil	2·988	2·845	2·342
November 17 -	·190	313·6	53	176·1	1,174	2	2	2	1	6·67	451,584	64,044	42,912	21,780	7,044	3·251	3·110	2·644
December 7 - -	·695	358·2	55	191·0	1,945	3	3	3	3	10·18	515,808	167,701	133,321	98,941	64,561	5·298	5·153	4·647
December 8 - -	·110	286·4	60	186·2	1,588	2	2	2	1	8·53	412,416	94,728	72,384	50,040	28,248	4·366	4·207	3·714
December 14 -	·415	313·3	89	187 2	1,545	2	2	1	1	8·25	451,152	77,628	55,164	36,540	25,308	4·329	4·093	3·597
Totals - -	11·295	8694·3	5431	4645·9	—	85	65	46	26	189·92	12,519,792	2,459,271	1,672,463	1,092,391	715,501	102·761	88·371	76·066
Average 26 days -	·434	334·4	208·9	178·7	—	—	—	—	—	7·30	—	—	—	—	—	3·952	3·399	2·926

TABLE No 22.—SUMMARY OF EFFECTS OF HEAVY FALLS OF RAIN, CROYDON.

Year	Number of days of heavy rainfall.	Average daily fall in time of heavy rainfall. Inches.	Total flow in sewer due to sewage and rainfall on days of heavy rainfall. Cube feet.	Total flow of sewage only on days of heavy rainfall. Cube feet.	Total flow in sewers due to rainfall on days of heavy rainfall. Cube feet.	Total flow of sewage and rainfall in excess of 3 times dry weather flow. Cube feet.	Percentage of flow of sewage and rainfall in excess of 3 times dry weather flow.	Total flow of sewage and rainfall in excess of 4 times dry weather flow. Cube feet.	Percentage of flow of sewage and rainfall in excess of 4 times dry weather flow.	Total flow of sewage and rainfall in excess of 5 times dry weather flow. Cube feet.	Percentage of flow of sewage and rainfall in excess of 5 times dry weather flow.	Total flow of sewage and rainfall in excess of 6 times dry weather flow. Cube feet.	Percentage of flow of sewage and rainfall in excess of 6 times dry weather flow.	Discharge of sewer at time of maximum flow with leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow without leakage. Cube feet per acre per minute.	Discharge of sewer at time of maximum flow Rainfall only. Cube feet per acre per minute.
1880	17	·681	11,034,144	5,205,600	5,828,544	2,067,803	18·740	1,166,556	10·572	564,106	5·112	203,747	1·847	4 886	4·078	3·409
1881	16	·533	8,852,688	4,753,152	4,099,536	1,381,137	15·601	774,778	8·752	383,550	4·333	185,172	2·092	4·986	3·998	3·346
1882	22	·441	11,782,224	6,471,792	5,310,432	1,880,874	15·964	1,153,764	9·792	748,794	6·355	535,527	4·545	4·303	3·442	2·838
1883	16	·425	7,847,280	4,692,096	3,155,184	881,853	11·238	467,548	5·958	235,600	3·002	147,048	1·874	4·376	3·389	2·804
1884	17	·461	8,754,768	4,605,696	4,149,072	1,387,973	15·854	860,366	9·827	508,711	5·811	292,297	3·339	3·932	3·409	2·883
1885	25	·440	12,978,000	6,630,768	6,347,232	2,142,862	16·511	1,145,734	8·828	520,048	4·007	194,748	1·501	3·410	3·028	2·527
1886	26	·434	12,519,792	6,690,096	5,829,696	2,459,271	19·643	1,672,463	13·359	1,092,391	8·725	715,501	5·715	3·952	3·399	2·926
Totals	—	3·415	73,768,896	39,049,200	34,719,696	12,201,773	113·551	7,241,209	—	4,053,200	—	2,274,040	—	29·845	24·743	20·733
Averages	—	·488	10,538,414	5,578,457	4,959,957	1,743,110	16·222	1,034,458	9·584	579,029	5·335	324,863	2·988	4·264	3·535	2·962

AVERAGE HOURLY DRY WEATHER FLOW, IN THE YEAR 1880. *

CUBE FEET PER MIN:



	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	Means.
Saturday	248·83	268·63	275·50	270·50	262·08	256·92	252·46	252·21	249·66	242·00	235·33	226·71	221·17	211·09	205·50	199·38	194·54	193·92	190·33	190·08	189·88	191·62	192·32	202·92	225·98
Friday	275·78	285·00	280·48	262·70	256·87	247·78	229·09	236·17	243·74	239·43	235·39	228·35	222·57	212·39	204·22	196·43	190·61	187·83	186·35	184·35	186·48	188·87	196·22	219·83	224·87
Thursday	256·20	260·13	268·86	251·13	246·26	238·07	239·06	240·80	237·66	234·33	226·53	219·33	218·60	209·40	201·93	202·40	188·00	185·13	185·00	183·13	184·87	198·86	213·40	234·07	221·79
Wednesday	270·50	268·40	272·50	260·70	253·15	245·50	249·00	229·50	239·70	234·85	230·35	223·25	217·85	209·35	202·65	197·50	192·40	189·45	188·10	186·85	187·15	191·05	216·25	225·40	224·22
Tuesday	239·20	265·85	270·70	253·20	250·00	244·85	245·70	247·10	247·40	238·35	234·30	226·85	222·95	212·60	204·00	201·40	191·95	188·15	187·65	186·60	188·40	196·10	209·20	227·85	224·18
Monday	260·47	260·19	267·71	253·71	250·86	242·71	244·62	218·71	237·33	233·80	230·47	233·14	222·43	214·76	207·62	202·04	197·14	192·04	191·62	189·67	190·90	196·09	212·09	227·90	224·08
Sunday	240·71	265·29	268·83	253·21	254·08	245·17	241·42	234·21	227·21	222·71	222·25	219·54	213·79	207·38	205·39	202·04	198·75	196·89	195·13	199·17	200·25	204·33	209·67	223·75	223·38

A.M. → ← P.M. → ← A.M →

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TABLE NO. 24.

CROYDON OUTFALL.

SEWER GAUGINGS.

January, 1881.

Date.		Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
January	1	—	903	700	203	—
„	2	—	901	691	210	—
„	3	—	917	707	210	—
„	4	·005	913	703	210	—
„	5	—	914	704	210	—
„	6	—	924	714	210	—
„	7	—	909	699	210	—
„	8	—	902	692	210	—
„	9	—	902	688	214	—
„	10	$\overset{\text{S}}{\cdot 01}$	914	700	214	—
„	11	$\overset{\text{S}}{\cdot 07}$	904	687	214	3
„	12	—	899	685	214	—
„	13	—	903	689	214	—
„	14	—	911	682	229	—
„	15	—	881	645	236	—
„	16	—	893	641	252	—
„	17	—	872	612	260	—
„	18	$\overset{\text{S}}{\cdot 40}$	907	640	263	4
„	19	$\overset{\text{S}}{\cdot 05}$	889	620	269	—
„	20	—	902	650	252	—
„	21	—	873	616	257	—
„	22	—	908	642	266	—
„	23	—	896	629	267	—
„	24	—	870	608	262	—
„	25	—	880	633	247	—
„	26	$\overset{\text{R \& S}}{\cdot 08}$	901	630	259	12
„	27	·07	988	665	262	61
„	28	·095	993	667	260	66
„	29	·255	1,079	670	254	155
„	30	·085	976	680	253	43
„	31	·01	929	669	260	—
Totals - - -		1·13	28,353	20,658	7,351	344
Averages - - -		10 days ·01 and over.	914·6	666·4	237·1	11·1

Table No. 24—(*continued*).

CROYDON OUTFALL.

Sewer Gaugings.

February, 1881.

Date.		Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
February	1	·015	940	680	253	7
"	2	·165	977	697	223	57
"	3	·07	977	714	248	15
"	4	·025	968	742	226	—
"	5	·005	995	764	231	—
"	6	—	1,006	786	220	—
"	7	·53	1,150	780	230	140
"	8	—	955	727	228	—
"	9	·30	1,021	770	227	24
"	10	·26	1,018	750	222	46
"	11	·01	987	782	205	—
"	12	—	990	780	210	—
"	13	—	1,011	801	210	—
"	14	·325	1,120	802	206	112
"	15	·095	1,108	833	207	68
"	16	·005	1,042	834	208	—
"	17	—	1,070	876	194	—
"	18	·01	1,077	861	216	—
"	19	·475	1,205	870	199	136
"	20	R. & S. ·24	1,203	894	175	134
"	21	—	1,182	975	207	—
"	22	·005	1,182	944	198	40
"	23	·495	1,216	966	200	50
"	24	—	1,272	1,073	199	—
"	25	—	1,202	1,005	197	—
"	26	S. ·01	1,207	1,011	196	—
"	27	S. ·01	1,210	1,016	194	—
"	28	—	1,218	1,023	195	—
Totals - - -		3·05	30,509	23,756	5,924	829
Averages - -		16 days ·01 and over.	1,089·6	848·4	211·6	29·6

TABLE NO. 24—(*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

March, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
March 1	—	1,221	1,006	215	—
„ 2	—	1,215	1,006	209	—
„ 3	·075	1,239	1,020	195	24
„ 4	·275	1,298	1,035	207	56
„ 5	·51	1,331	1,026	206	99
„ 6	·075	1,186	965	199	22
„ 7	·08	1,177	965	199	13
„ 8	·07	1,181	965	190	26
„ 9	·01	1,207	1,001	206	—
„ 10	—	1,231	1,027	204	—
„ 11	—	1,211	1,010	201	—
„ 12	—	1,242	1,039	203	—
„ 13	—	1,261	1,079	182	—
„ 14	—	1,258	1,048	210	—
„ 15	—	1,245	1,033	212	—
„ 16	—	1,245	1,032	213	—
„ 17	—	1,243	1,038	205	—
„ 18	—	1,176	969	207	—
„ 19	—	1,259	1,044	215	—
„ 20	·13	1,280	1,060	210	10
„ 21	R. & S. ·035	1,240	1,010	221	9
„ 22	·05	1,248	1,017	210	21
„ 23	·175	1,278	1,024	211	43
„ 24	·06	1,249	1,012	201	36
„ 25	—	1,222	1,011	211	—
„ 26	D ·005	1,231	1,020	211	—
„ 27	—	1,244	1,051	193	—
„ 28	—	1,235	1,016	219	—
„ 29	—	1,233	1,004	229	—
„ 30	—	1,206	1,001	205	—
„ 31	—	1,203	974	229	—
Totals - - - -	1·55	38,295	31,508	6,428	359
Averages - -	12 days ·01 and over.	1,235·3	1,016·3	207·5	11·5

TABLE No. 24.—(*continued.*)

CROYDON OUTFALL.

SEWER GAUGINGS.

April, 1881.

Date.		Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
April	1	—	1,196	997	199	—
„	2	—	1,204	973	231	—
„	3	—	1,201	981	220	—
„	4	—	1,203	969	234	—
„	5	—	1,193	961	232	—
„	6	—	1,165	951	214	—
„	7	—	1,179	961	218	—
„	8	—	1,173	947	226	—
„	9	—	1,153	930	223	—
„	10	—	1,151	934	217	—
„	11	·095	1,223	935	226	62
„	12	·025	1,137	890	223	24
„	13	·01	1,115	889	226	—
„	14	—	1,105	882	223	—
„	15	—	1,108	887	221	—
„	16	—	1,112	882	230	—
„	17	—	1,091	871	220	—
„	18	—	1,095	868	227	—
„	19	—	1,083	869	214	—
„	20	S. ·005	1,069	832	227	10
„	21	—	1,039	840	199	—
„	22	·005	1,025	817	208	—
„	23	·15	1,052	815	225	12
„	24	—	1,008	817	191	—
„	25	·005	1,009	805	204	—
„	26	·05	1,004	786	218	—
„	27	—	977	770	207	—
„	28	—	963	743	220	—
„	29	·065	963	740	217	6
„	30	·085	973	740	213	20
Totals - - -		·495	32,969	26,282	6,553	134
Averages - -		7 days ·01 and over.	1,099·0	876·1	218·4	4·5

TABLE NO. 24—*continued.*

CROYDON OUTFALL.

SEWER GAUGINGS.

May, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
May 1	·065	969	740	186	43
„ 2	·15	978	735	211	32
„ 3	—	926	712	214	—
„ 4	·02	933	723	210	—
„ 5	—	933	710	223	—
, 6	—	919	690	229	—
„ 7	—	911	674	237	—
„ 8	—	915	703	212	—
„ 9	—	901	663	238	—
„ 10	—	895	657	238	—
„ 11	—	880	651	229	—
„ 12	—	878	644	234	—
„ 13	—	870	635	235	—
„ 14	—	860	624	236	—
„ 15	·015	863	644	202	17
„ 16	·02	860	630	220	10
„ 17	·08	856	630	221	5
„ 18	·185	856	600	209	47
„ 19	—	823	614	209	—
„ 20	T. H. R. ·09	841	590	213	38
„ 21	—	797	583	214	—
„ 22	—	820	623	197	—
„ 23	—	800	562	238	—
„ 24	—	810	563	247	—
„ 25	·05	810	565	240	5
„ 26	·005	798	571	227	—
„ 27	—	783	557	226	—
„ 28	·22	812	557	228	27
„ 29	·02	772	548	205	19
„ 30	—	768	530	238	—
„ 31	—	763	517	246	—
Totals - - - - -	·92	26,600	19,445	6,912	243
Averages - - -	11 days ·01 and over	858·1	627·3	223·0	7·8

TABLE NO. 24—(*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

June, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
June 1	—	760	513	247	—
,, 2	—	754	491	263	—
,, 3	—	740	480	260	—
,, 4	—	736	474	262	—
,, 5	·61	856	476	209	171
,, 6	·24	748	478	207	63
,, 7	·115	731	480	222	29
,, 8	·005	686	481	205	—
,, 9	—	684	464	220	—
,, 10	—	691	471	220	—
,, 11	—	696	472	224	—
,, 12	—	711	510	201	—
,, 13	—	703	453	250	—
,, 14	—	687	446	241	—
,, 15	—	675	444	231	—
,, 16	·015	681	431	250	—
,, 17	·53	743	416	251	76
,, 18	·01	611	377	234	—
,, 19	—	592	385	207	—
,, 20	·02	605	357	248	—
,, 21	·06	645	359	243	43
,, 22	—	588	347	241	—
,, 23	—	584	340	244	—
,, 24	—	584	336	248	—
,, 25	·105	565	306	232	27
,, 26	—	546	315	231	—
,, 27	·01	576	347	229	—
,, 28	—	576	338	238	—
,, 29	—	565	324	241	—
,, 30	—	575	322	253	—
Totals - - -	1·72	19,894	12,433	7,052	409
Averages - - -	10 days ·01 and over.	663·1	414·4	235·1	13·6

TABLE NO. 24.—(*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

July, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
July 1	—	573	311	262	—
„ 2	—	564	288	276	—
„ 3	—	558	300	258	—
„ 4	—	564	287	277	—
„ 5	$^{\text{T}}$·575	633	290	254	89
„ 6	$^{\text{T}}$·16	620	290	245	85
„ 7	—	513	276	237	—
„ 8	·02	524	290	234	—
„ 9	—	515	275	240	—
„ 10	—	545	307	238	—
„ 11	—	571	329	242	—
„ 12	·01	589	347	242	—
„ 13	—	612	358	254	—
„ 14	—	615	350	265	—
„ 15	·03	615	340	275	—
„ 16	—	604	336	268	—
„ 17	—	599	365	234	—
„ 18	—	561	292	269	—
„ 19	·01	533	262	271	—
„ 20	·01	525	283	242	—
„ 21	·055	522	271	251	—
„ 22	·055	553	270	212	71
„ 23	·035	521	270	223	28
„ 24	·03	529	295	209	25
„ 25	—	521	295	226	—
„ 26	·02	521	288	227	6
„ 27	·01	524	266	246	12
„ 28	·175	509	265	222	22
„ 29	—	469	248	221	—
„ 30	·225	514	265	226	23
„ 31	·365	518	260	211	47
Totals - - -	1·785	17,134	9,169	7,557	408
Averages - - -	16 days ·01 and over.	552·7	295·8	243·8	13·1

TABLE No. 24 (*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

August, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
August 1	·05	462	240	222	—
„ 2	—	452	239	213	—
„ 3	—	489	259	230	—
„ 4	—	487	263	224	—
„ 5	—	489	261	228	—
„ 6	—	472	226	246	—
„ 7	—	478	291	187	—
„ 8	·395	551	241	229	81
„ 9	—	466	261	205	—
„ 10	·015	453	233	220	—
„ 11	·20	458	230	228	—
„ 12	1·23	841	250	209	382
„ 13	—	552	350	202	—
„ 14	—	511	303	208	—
„ 15	·03	516	265	219	32
„ 16	·05	520	265	241	14
„ 17	·265	571	275	220	76
„ 18	·03	493	271	222	—
„ 19	·03	541	275	210	56
„ 20	·015	541	324	217	—
„ 21	·405	607	275	169	163
„ 22	·03	479	255	224	—
„ 23	·195	526	255	218	53
„ 24	·07	476	250	208	18
„ 25	·51	649	250	209	190
„ 26	·14	501	290	188	23
„ 27	—	456	245	211	—
„ 28	·02	483	272	211	—
„ 29	·32	558	272	215	71
„ 30	·01	461	245	216	—
„ 31	·005	490	275	215	—
Totals - - -	4·015	16,009	8,186	6,664	1,159
Averages - - -	20 days ·01 and over	516·4	264·0	215·9	37·4

TABLE NO. 24—(*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

September, 1881.

Date.		Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
September	1	—	506	286	220	—
,,	2	·005	497	283	214	—
,,	3	—	509	293	216	—
,,	4	·01	504	313	191	—
,,	5	·345	599	293	217	89
,,	6	·04	474	246	219	9
,,	7	·01	477	278	199	—
,,	8	·04	463	224	224	15
,,	9	—	444	223	221	—
,,	10	·085	500	246	210	44
,,	11	·10	501	246	226	29
,,	12	·01	449	279	170	—
,,	13	—	449	234	215	—
,,	14	—	471	269	202	—
,,	15	·02	478	258	220	—
,,	16	—	477	264	213	—
,,	17	·08	482	261	221	—
,,	18	·05	465	245	216	4
,,	19	·025	450	235	205	10
,,	20	·27	527	235	201	91
,,	21	·035	428	232	196	—
,,	22	·28	467	230	203	34
,,	23	·01	409	215	184	10
,,	24	·50	563	230	208	125
,,	25	—	436	235	201	—
,,	26	·145	465	235	211	19
,,	27	·005	406	195	211	—
,,	28	—	418	259	159	—
,,	29	—	426	179	247	—
,,	30	—	419	206	213	—
Totals - - -		2·065	14,159	7,427	6,253	479
Averages - -		18 days ·01 and over	472·0	247·6	208·4	16·0

TABLE NO. 24—(*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

October, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
October 1	—	397	183	214	—
„ 2	—	382	177	205	—
„ 3	·01	373	163	210	—
„ 4	·02	374	148	217	9
„ 5	·02	373	157	216	—
„ 6	·04	380	161	208	11
„ 7	·23	432	165	207	60
„ 8	·41	548	170	209	169
„ 9	·015	382	174	208	—
„ 10	·01	377	152	225	—
„ 11	·005	383	177	206	—
„ 12	—	377	164	213	—
„ 13	·30	456	173	216	67
„ 14	—	394	182	212	—
„ 15	H ·03	385	165	220	—
„ 16	—	386	188	198	—
„ 17	—	386	178	208	—
„ 18	—	373	170	203	—
„ 19	—	375	178	197	—
„ 20	·19	415	168	219	28
„ 21	·005	366	163	203	—
„ 22	1·10	603	163	208	232
„ 23	·015	463	165	188	110
„ 24	—	401	177	224	—
„ 25	·01	392	193	199	—
„ 26	·03	396	170	218	8
„ 27	·005	386	171	215	—
„ 28	—	381	172	209	—
„ 29	H ·005	385	174	211	—
„ 30	—	380	179	201	—
„ 31	·005	391	182	209	—
Totals - - -	2·455	12,492	5,302	6,496	694
Averages - -	15 days ·01 and over	403·0	171·0	209·5	22·5

TABLE NO. 24—(*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

November, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
November 1	·02	371	173	198	—
" 2	·06	374	167	207	—
" 3	·13	405	172	204	29
" 4	·01	369	174	195	—
" 5	·255	470	172	193	105
" 6	·01	397	202	195	—
" 7	·01	361	169	192	—
" 8	—	365	161	204	—
" 9	—	360	174	186	—
" 10	—	377	182	195	—
" 11	·05	388	182	187	19
" 12	—	385	197	188	—
" 13	—	385	193	192	—
" 14	—	372	187	185	—
" 15	—	377	186	191	—
" 16	·23	416	186	176	54
" 17	—	370	175	195	—
" 18	·015	375	186	189	—
" 19	—	363	170	193	—
" 20	·25	421	170	197	54
" 21	·13	428	170	171	87
" 22	·10	377	170	189	18
" 23	—	368	173	195	—
" 24	·58	582	175	199	208
" 25	·41	617	200	193	224
" 26	H.R. 1·13	793	200	196	370
" 27	·17	603	254	205	144
" 28	—	498	292	206	—
" 29	·005	494	308	186	—
" 30	·05	499	280	204	15
Totals - -	3·615	12,960	5,827	5,806	1,327
Averages - -	18 days ·01 and over	432·0	194·2	193·6	44·2

TABLE No. 24—(*continued*).

CROYDON OUTFALL.

SEWER GAUGINGS.

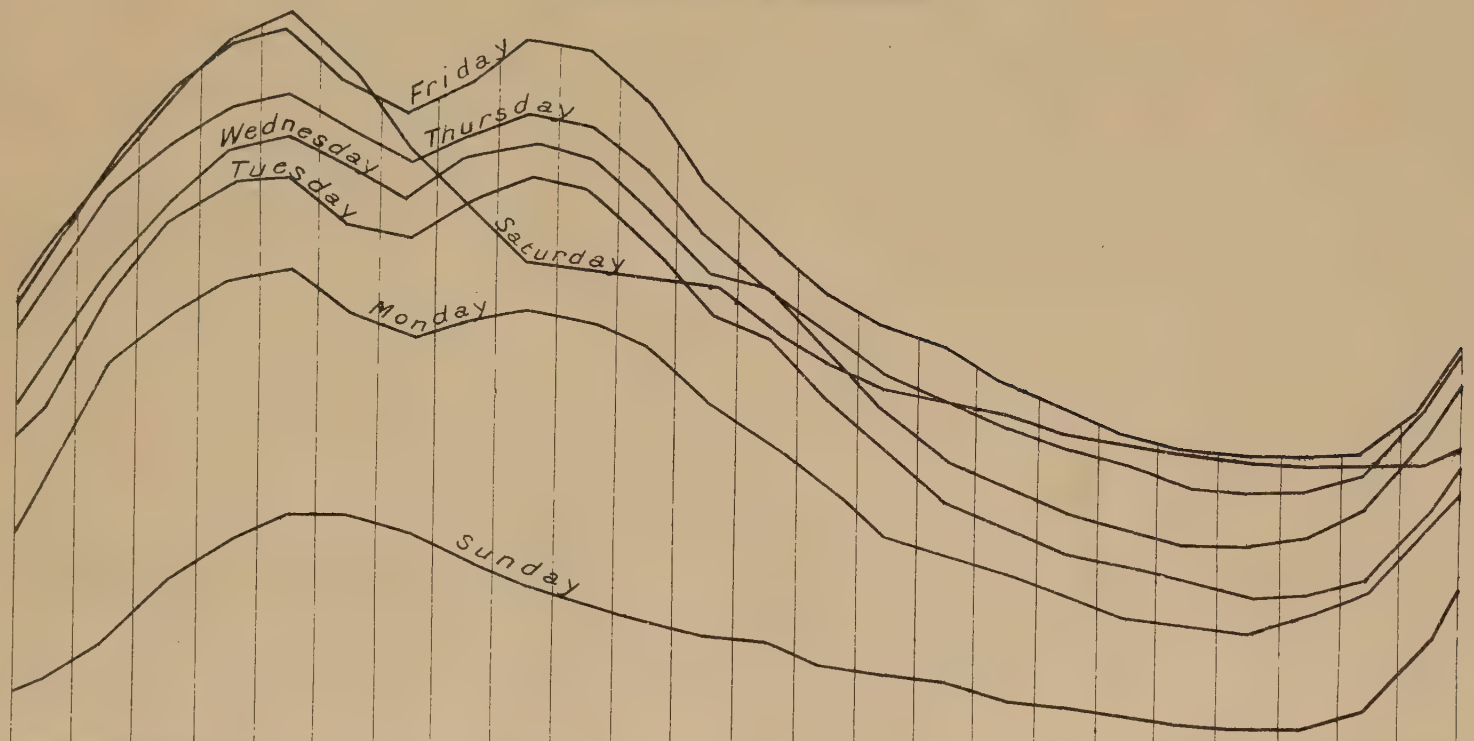
December, 1881.

Date.	Rain in inches.	Total Flow in Sewer. Cubic feet per minute.	Flow in Sewer due to Leakage. Cubic feet per minute.	Flow in Sewer due to Water Supply. Cubic feet per minute.	Flow in Sewer due to Rainfall. Cubic feet per minute.
December 1	·035	501	280	196	25
„ 2	·01	473	275	198	—
„ 3	—	480	263	217	—
„ 4	·01	472	276	196	—
„ 5	·13	512	263	204	45
„ 6	·555	654	263	187	204
„ 7	—	501	301	200	—
„ 8	·16	511	276	191	44
„ 9	s. ·18	541	280	179	83
„ 10	s. ·18	624	283	193	148
„ 11	·075	501	287	199	15
„ 12	·18	581	290	179	112
„ 13	—	497	294	203	—
„ 14	·06	523	295	201	27
„ 15	·04	518	282	196	40
„ 16	·255	506	300	177	29
„ 17	·555	781	305	201	275
„ 18	—	581	380	201	—
„ 19	·395	677	310	192	175
„ 20	·02	563	315	205	43
„ 21	—	572	381	191	—
„ 22	—	556	365	191	—
„ 23	·01	545	337	208	—
„ 24	—	551	332	219	—
„ 25	·01	542	366	176	—
„ 26	—	545	319	226	—
„ 27	—	543	337	206	—
„ 28	·005	580	371	209	—
„ 29	—	598	384	214	—
„ 30	—	596	406	190	—
„ 31	—	594	395	199	—
Totals	2·865	17,219	9,811	6,144	1,264
Averages	18 days ·01 and over.	555·5	316·5	198·2	40·8

SEWER GAUGINGS.

AVERAGE HOURLY DRY WEATHER FLOW, IN THE YEAR 1899.

CUBE: FEET: PER. MIN.



	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	Means.
Saturday	2944	3458	3860	4171	4334	4055	3567	3240	2954	2900	2861	2814	2591	2396	2239	2177	2121	2002	1960	1882	1846	1828	1833	1853	2745 · 25
Friday	3153	3670	4114	4415	4497	4198	4006	4196	4439	4376	4113	3661	3312	3034	2840	2718	2519	2358	2220	2138	2112	2114	2147	2404	3281 · 42
Thursday	3213	3725	4041	4252	4331	4134	3971	4125	4245	4193	3927	3527	3274	3040	2787	2620	2504	2365	2288	2155	2131	2140	2248	2638	3244 · 75
Wednesday	3029	3570	3985	4259	4360	4201	4010	4232	4331	4245	3959	3596	3505	3148	2814	2595	2405	2260	2175	2083	2083	2127	2278	2679	3247 · 04
Tuesday	3048	3674	4107	4343	4381	4113	4042	4251	4394	4334	3997	3641	3439	3142	2854	2561	2430	2283	2209	2127	2038	2069	2153	2495	3255 · 21
Monday	3895	3563	3837	4046	4124	3872	3747	3849	3900	3833	3693	3375	3157	2939	2631	2531	2426	2307	2175	2137	2096	2203	2346	2698	3099 · 17
Sunday	2000	2253	2597	2816	2982	2985	2892	2732	2610	2502	2393	2322	2290	2157	2095	2062	1960	1923	1860	1801	1779	1786	1903	2251	2289 · 63

← A.M. → ← P.M. → ← A.M. →

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REPORT

TO THE

ROYAL COMMISSION ON SEWAGE DISPOSAL ON THE FLOW OF SEWAGE AT STOCKPORT, MACCLESFIELD, AND ROCHDALE,

WITH

SPECIAL REFERENCE TO THE DISCHARGE FROM STORM OVERFLOWS,

BY

MR. R. A. TATTON, M.INST.C.E., CHIEF INSPECTOR TO THE MERSEY AND IRWELL JOINT COMMITTEE.

STORM WATER GAUGINGS.

The investigation into the sewage flow at Stockport, Macclesfield, and Rochdale was undertaken in order to obtain answers to some or all of the following questions with regard to the discharge from storm overflows:—

1. Assuming the overflows are fixed at such a point that they will not come into action until the sewage during that part of the day when it is flowing at the maximum rate is diluted with five times its volume of storm water, what may be expected to be the total volume of sewage and storm water delivered at the outfall during any one day of 24 hours in a town—

(*a*) Having a complete system of surface water sewers?

(*b*) Having no separate system?

2. During how many days in the year is it probable that this total volume will be delivered?

3. During how many hours in the year is it probable that the overflows would be operating, and can any indication be given of the total volume of sewage and storm water passing over the overflows as compared with that flowing to the outfall during the year?

4. During how many consecutive hours is it probable the overflows would be operating?

5. Can similar information be given assuming different dilutions?

6. What is the polluting quality of the liquid passing over the overflows at any given volume of flow, and at given times during the period of storms?

At Stockport the flow observations were taken at the outfall works, where the sewage is pumped, and the volume lifted by the pump calculated. The other observations were taken by means of automatic recording gauges. The gauge at Macclesfield recorded the flow over a rectangular notch at the entrance to the outfall works; the gauge at Rochdale recorded the flow through a circular sewer 9ft. diameter.

Particulars of the Areas controlled by the Sewers under observation are as follows:—

——	Stockport.	Macclesfield.	Rochdale.
Area to gauge - -	2,970 acres	475 acres	1,300 acres
Population - -	87,500	34,635	45,000
Distance from extreme point of collecting sewer to gauge.	5 miles.	4⅜ miles	—
Fall from extreme point of collecting sewer to gauge.	128 feet,	185 feet	—

In all three cases surface water is admitted into the sewers.

These places were selected as being towns of considerable size, where the flow of sewage to the point where the gauge was fixed was least interfered with by storm overflows. Ideal conditions where the whole of the sewage and storm water finds it way to the outfall works do not exist at any large towns in the Mersey and Irwell watershed, and at each of the three selected places during times of storm there was a flow of sewage which it was impossible to gauge from storm overflows above the point where the gaugings were taken.

The gaugings of which returns are sent in were taken at Stockport between July 20th, 1901, and February 28th, 1903; at Macclesfield between July 28th, 1901, and March 19th, 1903; at Rochdale between July 9th, 1902, and March 18th, 1903.

Basis of dilution calculations:—To arrive at the curve of average hourly variation of flow in dry weather, days in which there was no rainfall were taken in each of the years 1901 and 1902 in the months of May to October inclusive. These days were classified according to the days of the week, the flow at each hour ascertained, and the values averaged. From these average values a curve of hourly variations in dry weather for each day of the week was constructed, and on these curves all calculations of the amount of dilution as measured by the rate of flow are based. On this basis are constructed the Storm Water Records on Table A (1).

In order to answer Question 1 a different basis of calculation is required, and an average maximum dry weather rate of flow has been taken. The maximum rate of flow varies as between one day and another, and also as regards the hour of its arrival—that is to say, it may arrive some hours later on Mondays than on Tuesdays. The average maximum dry weather rate of flow is the average of the maximum rates attained each day. On this basis are constructed the Storm Overflow Records on Table A (2).

Answers to Questions based on Macclesfield.

Question 1. It is impossible to answer this question, as there was a storm overflow on the Macclesfield sewer between the town and the gauge which came into action when the sewage at its maximum dry weather rate of flow was diluted by one and a half times its volume of storm water—that is to say, when the flow was two and a half times its maximum dry weather rate.

The overflow did not take the whole of the water above two and a half times, as is shown by the gaugings, but reduced the flow considerably, and the gaugings, therefore, at Macclesfield are taken subject to this overflow.

Question 2. The Macclesfield gaugings show that with the storm overflow fixed so that it comes into action when the flow of sewage is equal to two and a half times the maximum rate, the volume delivered at the outfall works between July 25th, 1901, and March 19th, 1903, was on

25 days equal to 3 times the average dry weather discharge.
7 days equal to 3½ times the average dry weather discharge.
3 days equal to 4 times the average dry weather discharge.
1 day equal to 5 times the average dry weather discharge.

Question 3. Table A (2) shows when the storm overflow was working, set as it was to come into action at two and a half times the average maximum rate of flow in dry weather. Between July 25th, 1901, and March 19th, 1903, it came into action on 168 days, and was in action for 436½ hours out of the total number of 14,472 hours covered by the period.

Question 4. The Macclesfield overflow was in action during 13½ hours on November 11th, 1901, of which 10½ hours were consecutive. On November 12th, 1901, it was in action during 13¾ hours, of which eight hours were consecutive. (*See* Table A (2)).

Considering the question from the point of view of the Macclesfield conditions, and taking November 11th, 1901, for our investigations, we see from Table A (1) that the total volume of sewage delivered at the outfall works on that day was equal to three times the dry weather flow, that the maximum rate of flow varied between three and nine times the dry weather rate, and that the sewage was flowing at and above three times the dry weather rate for 16 hours 55 minutes. On referring to Table A (2) for the same date, we find that the storm overflow, which comes into action when the flow of sewage equals two and a half times the maximum dry weather rate, was working for 13½ hours only—that is to say, that for the remaining three and a half hours of the day the sewage did not flow at the rate of two and a half times the maximum rate for the day, although it did flow at a rate greater than three times the dry weather rate of those particular hours.

STOCKPORT

The observations at the Stockport Outfall Works were taken under the following conditions:—The sewage was pumped intermittently at the outfall works, so that it was impossible to ascertain accurately the hourly variation of flow; the day was therefore divided into eight three-hourly intervals in order to eliminate as far as possible the effect of the intermittent pumping.

This arrangement also averages any short periods of a high rate of flow; for instance, referring to Table B (1), December 8th, 1901, the average rate of flow between 6 a.m. and 9 a. m. was nine times the dry weather rate, but during part of this period it was considerably higher, and during part it was lower. The pumps at Stockport are capable of dealing with about six times the maximum rate of flow, they will therefore deal with a volume equal to or somewhat greater than an overflow which will not come into action until this rate has been reached.

On this basis, during the period of observation at Stockport, between July 21st, 1901, and February 26th, 1903, the volume delivered at the outfall works was on

21 days equal to 2½ times the average dry weather discharge.
5 days equal to 3 times the average dry weather discharge.
2 days equal to 3½ times the average dry weather discharge.

There are a considerable number of storm overflows on the main outfall sewer in the form of leaping weirs, which come into action at varying rates of flow, and no estimate can be given of the volume discharged by them.

The Stockport observations assist somewhat towards the solution of Questions 1 and 6, but are useless for the remainder. Storm water samples were taken on 2 days.

Owing to the amalgamation of Reddish with Stockport, the Reddish sewage commenced to flow to the Stockport outfall on July 10th, 1902, and allowance has been made for this in the calculations.

ROCHDALE.

The Rochdale gaugings are unfortunately not reliable, as they were interfered with not only by storm overflows, but also by variations in the gradient of the sewer to which the gauging instrument was connected. It was also found impossible to prevent silt obstructing the channel connecting the sewer with the chamber in which the float, which was attached to the automatic machinery was suspended.

In order correctly to answer the questions which have been put, ideal conditions are required, which do not exist at any of the places under observation, and it would be dangerous to draw from these observations general conclusions as to what volume should be treated.

Information obtained from one place might be quite misleading if reliance were placed upon it as the basis for another. Each case must be taken on its own merits, and observations taken not only of the quantity, but also of the quality of the liquid being discharged from the storm overflows, and also of its effect upon the stream.

The standard which has been adopted by the Local Government Board, namely, that six times the dry weather rate of flow shall be treated, seems to be a reasonable standard for the present, or until we have further information to go upon, but it should not be permanently fixed by statute or allowed as an answer to a charge of pollution. In certain cases, particularly in hilly districts where the sewage is discharged rapidly to the outfall works, it will probably be found that a higher rate of dilution will be necessary to prevent pollution.

From experience on the rivers it is found that most harm is done by storm overflows when heavy storms occur during otherwise dry weather in summer. This was very noticeable during the drought of last summer in the Bollin below Macclesfield, and in the Roach below Rochdale.

A heavy thunderstorm brought the storm overflows into action, and a large volume of sewage containing much suspended matter was discharged from them, when the stream itself was extremely low and quite incapable of carrying the suspended matter forward. The result was that the banks and bed of the stream were covered with a highly offensive deposit of black mud. To prevent such an occurrence taking place the sills would have to be fixed at a very high level, especially in hilly districts, but the total volume to be dealt with at the outfall works need not necessarily be excessive if the high rate of flow was due to a short although severe storm.

Diagrams A and C at the end of the tables show the average hourly dry weather flow in the year 1902 to the Macclesfield and Rochdale gauges.

Diagram B shows the flow during certain typical storms gauged at Macclesfield.

During the period under observation storm water samples were taken at varying amounts of dilution and submitted to Dr. McGowan for chemical and to Dr. Houston for bacteriological report. They have kindly furnished me with the results of their investigations (see Addenda to this Report, pages 177 and 187), from which it is evident that storm water, even when diluted to a volume equal to seven times the dry weather rate, is liable to be bad. The solids in suspension are very high, and it would be of great value to know whether settlement in tanks alone would be sufficient to remove the impurities. If this were the case, an increase in the tank capacity at outfall works to provide for storm water might effect a considerable saving in the cost of storm water filter beds.

R. A. TATTON

TABLE A (1).

MACCLESFIELD STORM WATER RECORD.

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1901.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
July 25th, Thursday - -	3.15 a.m.–4.30. a.m.	1	15	7½	—	10	1·64	—	1,716,624	
				6	—	35				
				5	—	45				
				4	—	50				
" , - -	Noon–6.45 p.m.	6	45	4	—	45	—	—	—	
July 25th, Thursday, and July 26th, Friday	10 p.m.–1.0 a.m.	3	—	7	—	20	—	—	—	
				6	1	—				
				5	2	15				
				4	2	30				
July 26th, Friday - - -	9.15 p.m.–9.4 p.m.	—	30	—	—		0·04	—	947,856	
July 28th, Sunday - - -	1.40 a.m.–4.40 a.m.	3	—	10	—	30	0·32	1.0 a.m.–4.0 a.m.	987,168	
				8	1	45				
				6	2	15				
				5	2	30				
				4	2	45				
" " - -	3.30 p.m.–5.35 p.m.	2	5	5½	—	30	—	2.30 p.m.–4.30 p.m.	—	
				5	—	50				
				4	1	45				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1901.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
August 10th, Saturday - -	10.0 p.m.–10.30 p.m.	—	30	4	—	20	0·01	7.0 p.m.	537,264	
August 14th, Wednesday -	5.45 a.m.–7.15 a.m.	1	30	6½	—	5	0·33	Midnight–2.0 a.m.; 9.30–noon; 5.0 p.m. – 11.0 p.m.	917,280	
				6	—	30				
				5	—	45				
				4	1	10				
August 15th, Thursday - -	5.10 a.m.–7.45 a.m.	2	35	7	—	30	0·02	1.30 a.m.	963,100	
				6	1	45				
				5	2	15				
				4	2	20				
August 26th, Monday - -	12.45 a.m.–3.45 a.m.	3	—	9	—	20	0·74	1.0 a.m.–3.0 a.m.	1,174,992	
				7	1	20				
				6	2	—				
				5	2	5				
				4	2	15				
,, ,, - -	2.45–3.15 p.m.; 3.30–3.35 p.m.; 4.40–5.0 p.m.; 6.45–7.15 p.m.	1	25	—	—	—	—	4.0 p.m.–8.0 p.m.	—	
August 28th, Wednesday -	6.15–7.20 a.m.;	1	5	5	–	45	0·17	5.30 a.m.–7.0 p.m.	906,360	
,, ,, - -	1.20–1.40 p.m.	—	20							
August 29th, Thursday - -	10 p.m.–11.30 p.m.	1	30	5	—	45	0·16	7.0 p.m.–11.0 p.m.	729,456	
				4	1	10				
August 31st, Saturday - -	12.20 a.m.–3.45 a.m.	3	25	7	1	—	0·17	1.0 a.m.–3.30 a.m.	786,380	
				6	2	30				
				5	2	45				
				4	3	—				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1901.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
September 8th, Sunday -	7.30 a.m.–8.30 a.m.; 9.30 a.m.–10.45 a.m.	2	15	6	—	25	0·15	6.30 a.m.–8.0 a.m.; 9.0 a.m.–noon	626,900	
				5	—	45				
				4	2	—				
September 16th, Monday -	8.15 p.m.–9.0 p.m.	—	45	—	—	—	0·10	7.30 p.m.–9.30 p.m.	792,792	
September 17th, Tuesday -	12.30 a.m.–1.30 a.m.	1	—	5	—	30	0·43	Midnight–1.15 a.m.	1,146,575	
				4	—	45				
" " -	2.15 p.m.–2.35 p.m.; 6.0 p.m.–6.20 p.m.; 7.20 p.m.–9.30 p.m.	2	50	—	—	—	—	2.0 p.m. & 5.30–9.0 p.m.	-	
September 20th, Friday -	11.0 a.m.–11.20 a.m.	—	20	—	—	—	0·10	11.0 a.m.–noon & at 9.0 p.m.	663,936	
September 21st, Saturday -	8.45 p.m.–9.15 p.m.	—	30	—	—	—	0·05	3.0 p.m.–4.30 p.m.	—	
September 25th, Wednesday -	7.30 p.m.–8.30 p.m.	1	—	4	—	15	0·07	6.0 p.m.–6.30 p.m.	631,176	
September 28th, Saturday -	9.45 p.m.–10.25 p.m.	—	40	4	—	15	—	—	607,152	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
1901.										
October 1st Tuesday - -	12.40 a.m.-2.20 a.m.; 8.45 a.m.-9.15 a.m.; 11.20 p.m.-11.50 p.m.	2	40	8 6 5 4	— 1 1 1	20 — — 15	0·28	1.45 a.m.-2.15 a.m.; 9.0 a.m.-1.0 p.m.; 11.0 p.m.-midnight.	794,975	
October 2nd, Wednesday -	Midnight-1.40 a.m.	1	40	7½ 6 5 4	— 1 1 1	30 5 20 30	—	Due to 0·17 ins. rainfall between 11.0 p.m. and midnight of previous day.	694,512	
October 3rd, Thursday - -	10.15 p.m.-midnight.	1	45	7 6 5 4	— — 1 1	30 40 35 45	0·23	9.15 p.m.-midnight.	832,104	
October 4th, Friday - -	Midnight-5.5 a.m.	5	5	8 7 6 5 4	— 1 2 4 4	20 15 30 30 50	0·28	Midnight-5.0 a.m.	945,672	
October 5th, Saturday - -	4.30 p.m.-5.15 p.m.; 7.0 p.m.-7.40 p.m.; 8.45 p.m.-9.30 p.m.; 10.40 p.m.-11.35 p.m.	3	5	5 4	— 1	20 20	0·17	1.15 p.m.-11.0 p.m.	779,688	
October 6th, Sunday - -	7.15 a.m. - 11.30 a.m.; 12.15 p.m.-12.55 p.m.; 1.30 p.m.-2.40 p.m.	6	20	7 6 5 4	1 2 3 4	— 40 10 —	0·62	7.30 a.m -2.30 p.m.	1,048,320	Storm water samples taken: 3 times D.W.F. - - 12.20 p.m. 4 " " - - 12.50 " 3 " " - - 2.30 "
October 7th, Monday - -	6.30 a.m.-7.0 a.m.	—	30	4	—	15	0·04	7.30 a.m. and 11.30 a.m.	808,080	
October 8th, Tuesday - -	12.20 a.m.-1.20 a.m.; 2.20 a.m.-3.40 a.m.; 7.0 a.m.-8.10 a.m.	3	30	8 7 6 5 4	— — 1 1 2	10 30 5 35 —	0·65	1.45 a.m.-2.30 a.m.; 4.0 a.m.-4.30 a.m.; 8.0 a.m.-9.0 a.m.; 1.0 p.m.-11.0 p.m.	1,594,675	

October 8th, Tuesday	6.40 p.m.–midnight.	5	20	5 4	— 3	30 30	—	—	—
October 9th, Wednesday	Midnight–1.20 a.m.; 2.10 a.m.–8.50 a.m.	8	—	8 7 6 5 4	1 2 4 5 6	5 30 — 10 —	0·36	1.0 a.m.–10.0 a.m.	1,679,496
October 11th, Friday	12.30 a.m.–12.50 a.m.	—	20	—	—		0·03	10.0 p.m.–11·0 p.m. on Thursday, 10th.	742,560
October 12th, Saturday	3.10 a.m.–4.20 a.m.	1	10	6 5 4	— — 1	20 45 5	0·07	1.30 a.m.–3.0 a.m.	718,600
October 13th, Sunday	3.35 a.m.–4.15 a.m.; 10.0 a.m.–10.30 a.m.; 11.0 a.m.–11.30 a.m.	1	30	5 4	— —	15 25	0·11	3.0 a.m.; 4.0 a.m.; 9.30 a.m.; 10.30 a.m.–11.0 a.m.	657,500
October 17th, Thursday	1.40 a.m.–5.40 a.m.; 1.15 p.m.–1.45 p.m.	4	30	6½ 6 5 4	— 1 2 3	20 45 30 —	0·18	1.0 a.m.–4.45 a.m.; 1.0 p.m.–1.30 p.m.	912,912
October 18th, Friday	1.45 p.m.–2.20 p.m.	—	35	—	—		0·22	11.0 a.m.–1.0 p.m.; 2.0 p.m.–2.30 p.m.	803,712
October 23rd, Wednesday	11.20 p.m.–midnight.	—	40	5 4	— —	30 40	0·04	11.0 p.m.–11.15 p.m.	716,352
October 24th, Thursday	11.10 a.m.–1.30 p.m.; 5.30 p.m.–6.30 p.m.	2	20	—	—		0·57	9.30 a.m.–12.30 p.m.; 5.0 p.m.–5.30 p.m.	1,192,464
October 25th. Friday	1.15 a.m.–3.40 a.m.; 9.40 a.m.–10.20 a.m.	3	5	9 7 6 5 4	— — 1 1 2	20 50 15 25 —	0·15	12.30 a.m.–2.0 a.m.; 9.0 a.m.–9.45 a.m.	693,400

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1901.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
November 10th, Sunday	10.20 p.m.–midnight.	1	40	7 6 5 4	— 1 1 1	45 40 40 40	0·50	11.0 p.m.–midnight.	742,600	
November 11th, Monday	Midnight–8.45 a.m.; 1.40–3.50; 6.0 p.m.–midnight.	16	55	9 8 7 6 5 4	— 1 3 4 8 10	30 40 15 35 30 —	0·50	Midnight to 9.0 a.m.; 5.0 p.m.–midnight.	2,184,000	Total volume delivered at outfall=3 times the average dry weather discharge.
November 12th, Tuesday	Midnight–8.50 a.m.; 1.50–3.20; 8.15 p.m.–midnight.	14	5	11 10 8 6 5 4	— 3 5 8 8 8	30 15 30 — 15 30	1·55	Midnight–noon; 6.0 p.m.–6.15 p.m.	1,945,981	Storm Water Samples taken: 4 times the D.W.F. ... 2.0 p.m. 3 ,, ,, ,, ... 2.30 p.m. 3½ ,, ,, ,, ... 3.15 p.m. Total volume delivered at outfall=3 times average dry weather discharge.
November 13th, Wednesday	Midnight–6.0 a.m.	6	—	—	—		0·03	6.0 a.m.	1,144,500	
November 18th, Monday	3.15 a.m.–4.15 a.m.; 6.20 a.m.–7.30 a.m.; 8.30 p.m.–midnight.	5	30	6½ 6 5 4	— — 1 3	20 30 20 10	0·29	Midnight–6.15 a.m.; 8.0 p.m.–midnight.	1,157,500	
November 19th, Tuesday	Midnight–3.5 a.m.; 7.10 a.m.–8.30 a.m.	4	25	7 6 5 4	— 2 2 3	30 30 40 35	0·26	Midnight–1.30 a.m.; 6.15 a.m.–12.30 p.m.	1,402,275	
November 20th, Wednesday	Midnight–4.20 a.m.; 8.45 a.m.–10.30 a.m; noon–midnight.	18	5	8 6 5 4	— 2 3 4	20 45 30 45	0·78	1.0 a.m.–3.45 a.m.; 9.45 a.m.–7.0 p.m.	2,088,000	Total volume delivered at outfall=3½ times dry weather discharge.
November 21st, Thursday	Midnight–9.0 a.m.; 8.45 p.m.–midnight.	12	15	8 7 6 5 4	1 3 3 5 9	30 — 30 45 —	0·44	5.15 a.m.–10.0 a.m.; 7.50 p.m.–midnight.	1,817,300	Total volume delivered at outfall=3 times average dry weather discharge.
November 22nd, Friday	Midnight–9.30 a.m.	9	30	7 6 5 4	5 7 7 8	— — 30 15	0·30	Midnight–9.0 a.m.	1,778,000	Total volume delivered at outfall=3 times average dry weather discharge.

Macclesfield Storm Water Record—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1901.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
December 5th, Thursday -	7.30. p.m.–midnight.	4	30	6	—	45	0·11	6.0 p.m.–10.0 p.m.	1,072,500	
				5	—	50				
				4	1	40				
December 7th, Saturday -	6.30. a.m.–8.0 a.m.; 9.30 p.m.–midnight.	4	—	8	1	—	0·25	4.30 a.m.–7.0 a.m.; 9.0 p.m.–midnight.	1,207,800	
				7	2	—				
				6	3	30				
				5	3	40				
				4	3	45				
December 8th, Sunday -	Midnight–midnight.	24	—	12	1	30	0·50	Midnight–2.0 a.m.; 6.0 p.m.–9 a.m.; 7.0 p.m.–8.0 p.m.	2,217,000	Total volume delivered at outfall = 5 times average dry weather discharge.
				10	4	30				
				8	6	—				
				6	9	30				
				5	11	—				
				4	13	—				
December 9th, Monday -	Midnight – 8.20 a.m.; 12.45 p.m. – 3.45 p.m.; 7.30 p.m. – 8 45 p.m.; 10.30–midnight.	14	5	9	—	30	0·24	1.0 a.m.–1.30 a.m.; at 3.0 a.m. & 5.0 a.m.; 1.45 p.m.–5.45 p.m.; 7.0 p.m.–midnight.	1,896,000	
				8	—	45				
				6	1	45				
				5	4	—				
				4	6	—				
December 10th, Tuesday -	Midnight-7.0 a.m.; 9.0 p.m.–midnight.	10	—	7	1	—	0·19	Midnight–3.0 a m.; 5.0 a.m.; 8.15 a.m.–9.0 a.m.; 8.0 p.m.–10.0 p.m.	1,952,775	Total volume delivered at outfall = 3 times average dry weather discharge.
				6	3	—				
				5	4	15				
				4	8	30				
December 11th Wednesday -	Midnight – 8.45 a.m.; 5.15 p.m. – 5.45 p.m.; 10.45–midnight.	10	30	7	—	10	0·09	2.0 p.m.–6.0 p.m.	1,826,000	Total volume delivered at outfall = 3 times average dry weather discharge.
				6	2	30				
				5	3	—				
				4	7	15				
December 12th, Thursday -	Midnight–7.0 a.m.; 4.15–midnight.	14	45	6	—	45	0·45	1.0 p.m.–midnight.	1,760,000	Total volume delivered at outfall = 3 times average dry weather discharge.
				5	1	50				
				4	4	—				

MACCLESFIELD STORM WATER RECORD—(*continued*)

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1901.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
December 13th, Friday - -	Midnight–10.0 a.m.; 8.0 p.m.–midnight.	14	—	8 6 5 4	4 7 8 10	— 30 30 15	0·14	Midnight–4.30 a.m.; 7.30 p.m.–10.30 p.m.	2,210,500	Total volume delivered at outfall=3½ times average dry weather discharge.
December 14th, Saturday -	Midnight–7.30 a.m.; 5.45 p.m.–7.0 p.m.	8	45	6 5 4	— 4 7	45 20 —	0·07	3.0 p.m.–6.0 p.m.	1,535,000	Total volume delivered at outfall=3½ times average dry weather discharge.
December 15th, Sunday - -	3.30 a.m.–7.15 a.m.	3	45	—	—		—	Due to rainfall on 14th.	882,500	—
December 16th, Monday -	8.0 p.m.–midnight.	4	—	4	1	45	0·21	10.0 a.m.–noon; 5.30 p.m.–10.0 p.m.	1,402,000	—
December 17th, Tuesday -	Midnight–3.15 a.m.; 9.10 p.m.–midnight.	6	5	4	4	15	0·07	9.0 p.m.–midnight.	1,474,275	—
December 18th, Wednesday -	Midnight–7.0 a.m.	7	—	—	—		0·01	5.0 p.m.	1,256,000	—
December 23rd, Monday -	6.20 p.m.–midnight.	5	40	5 4	1 2	15 30	0·34	3.30 p.m.–10.30 p.m.	1,474,250	—
December 24th, Tuesday -	Midnight–9.30 a.m.	9	30	8 6 5 4	4 7 7 8	— — 45 30	—	Due to rainfall on 23rd.	2,024,775	Total volume delivered at outfall=3 times average dry weather discharge.
December 25th, Wednesday -	5.0 a.m.–6.20 a.m.; 1.45 p.m.–3.30 p.m.; 5.5 p.m.–5.30 p.m.; 5.40 p.m.–midnight.	9	50		1	10	—	—	1,529,000	—

December 26th, Thursday -	3.0 a.m.-3.25 a.m.; 6.5 p.m.-6.45 p.m.; 9.20 p.m.-midnight.	3	45	—	—		—	—	1,629,300	
December 27th, Friday -	Midnight-7.0 a.m.	7	—	—	—		—	—	1,255,500	
December 28th, Saturday -	4.30 p.m.-midnight.	7	30	7 6 5 4	— 1 4 5	30 45 20 40	—	—	1,679,500	Total volume delivered at outfall=3 times average dry weather discharge.
December 29th, Sunday -	Midnight-10.0 a.m.; 8.0 p.m.-midnight.	14	—	6 5 4	1 2 4	— 20 —	—	—	1,670,500	Total volume delivered at outfall=3⅓ times average dry weather discharge.
December 30th, Monday -	Midnight-1.0 a.m.; 6.0 a.m.-9.0 a.m.	4	—	7 6 5 4	— 1 2 2	45 50 — 20	—		1,620,500	
December 31st, Tuesday -	12.30 a.m.-7.0 a.m.; 6.0 p.m.-midnight.	12	30	7 6 5 4	1 1 2 3	— 35 40 30	0·50	5.0 p.m.-midnight.	1,766,775	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
January 1st, Wednesday -	Midnight–3.20 a.m.; 9.0 p.m.–midnight.	6	20	9 8 6 5 4	2 5 7 8 9	— — 15 30 30	0·15	Midnight–2.0 a.m.; 10.0 p.m.–midnight.	2,356,800	Total volume delivered at outfall=4 times average dry weather discharge.
January 2nd, Thursday - -	Midnight–9.30 a.m.; 10.0–10.30 a.m; 11.5–11.25 a.m.; 11.0 p.m.–midnight.	11	20	7 6 5 4	1 1 6 7	— 40 30 15	0.13	Midnight–11.0 a.m.	1,826,500	Total volume delivered at outfall=3 times average dry weather discharge.
January 3rd, Friday - -	Midnight–7.30 a.m.	7	30	—	—		—	—	1,378,200	
January 4th, Saturday - -	2.30 a.m.–midnight.	21	30	8 6 5 4	1 2 3 12	30 45 35 10	—	—	2,199,300	Storm Water Samples taken: 4½ times the D.W.F. ... 2.0 p.m. 4 ,, ,, ,, ... 3.0 ,, 3½ ,, ,, ,, ... 4.0 ,, Total volume delivered at outfall=4 times average dry weather discharge.
January 5th, Sunday - -	Midnight–9.30 a.m.; 9.15 p.m.–midnight.	12	15	5 4	3 8	30 30	0·02	1.30 a.m.	1,360,800	Total volume delivered at outfall=3 times average dry weather discharge.
January 6th, Monday - -	Midnight–7.0 a.m.	7	—	—	—		0·01	6.0 a.m.	1,317,000	
January 10th, Friday - -	3.15 a.m.–7.45 a.m.; 7.45 p.m.–9.20 p.m.	6	5	7 6 5 4	2 3 4 4	30 15 — —	0·09	2.0 a.m.–6.0 a.m.	1,301,600	
January 11th, Saturday -	12.30 a.m.–1.50 a.m.	1	20	5 4	— 1	45 —	—	—	991,700	
January 12th, Sunday - -	4.30–5.30 a.m.	1	—	4	—	30	—	—	823,500	

January 23rd, Thursday - -	4.15 a.m.–7.30 a.m.	3	15	6	1	30	—	—	926,200	
				5	1	50				
				4	2	25				
January 25th, Saturday - -	2.20 a.m.–5.0 a.m.; 4.0 p.m.–5.30 p.m.	4	10	—	—	—	0·18	11.0 a.m.–4,30 p.m.	1,218,800	
January 27th, Monday - -	7.0 p.m.–midnight.	5	0	5	1	—	0·24	10.30 a.m.–8.0 p.m.	1,480,700	
				4	2	5				
January 28th, Tuesday - -	Midnight–8.30 a.m.	8	30	10	1	—	0·12	3.0 a.m.–4.0 a.m.	2,044,280	Total volume delivered at outfall = 3 times average dry weather discharge.
				8	1	15				
				6	6	—				
				5	7	10				
				4	7	40				

MACCLESFIELD STORM WATER RECORD—(*continued.*)

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
February 22nd, Saturday -	11.0 p.m.–midnight.	1	0	—	—	—	0·04	10 p.m.–midnight.	1,114,000	
February 23rd, Sunday - -	Midnight–2·30 a.m.	2	30	6	—	45	0·07	Midnight–1.0 a.m.	852,000	
				5	1	15				
				4	2	5				
February 27th, Thursday -	Midnight–4.15 a.m.	4	15	7	1	—	0·15	Midnight–3.0 a.m.	1,162,000	
				6	2	45				
				5	3	10				
				4	3	25				
February 28th, Friday - -	1.50 a.m.–3.45 a.m. 3.40 p.m.–4.10 p.m.	2	25	6	—	10	0·04	Midnight–1.0 a.m.	1,048,300	
				5	—	30				
				4	—	45				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
March 8th, Saturday - -	4.30 a.m.–5.40 a.m. 8.0 p.m.–11.20 p.m.	4	30	5	—	30	0·21	4.30 a.m.–7.0 a.m.; 7.0 p.m.–10.0 p.m.	921,800	
				4	3	50				
March 9th, Sunday - -	1.45 a.m.–3.25 a.m.; 9.0 p.m.–10.0 p.m.	2	40	6	1	—	0·09	2.0 a.m.–3.0 a.m. 8.30 p.m.–10.0 p.m.	821,300	
				5	1	5				
				4	1	30				
March 10th, Monday - -	1.10 a.m.–2.20 a.m.; 4.50 a.m–8.30 a.m.	4	50	5	2	45	0·14	2.0 a.m.–9.0 a.m.	1,015,500	
				4	3	45				
March 13th, Thursday - -	9.30 p.m.–10.0 p.m.; 10 45 p.m.–midnight.	2	15	6	—	30	0·10	8.0 p.m.–11.30 p.m.	915,800	
				5	1	—				
				4	1	30				
March 14th, Friday - -	Midnight–12.45 a.m.; 5.45 a.m.–6.20 a.m.; 7.45 p.m.–midnight.	5	35	5	1	50	0·33	6.30 p.m.–11.30 p.m.	1,230,000	
				4	4	—				
March 15th, Saturday - -	Midnight–6.0 a.m.	6	0	5	1	—	0·03	1.0 a.m. and at 4.0 a.m., due to rainfall on 14th.	1,067,000	
				4	2	—				
March 19th, Wednesday -	2.20 a.m.–3.0 a.m.; 3.40 a.m.–6.40 a.m.	3	40	6	—	20	0·14	1.30 a.m.–6.30 a.m.	834,400	
				5	2	—				
				4	2	30				
March 20th Thursday - -	3.0 a.m.–3.45 a.m.; 5.30 a.m.–7.45 a.m.	3	30	8	—	20	0·19	3.0 a.m.–9.0 a.m.	1,010,900	
				6	1	20				
				5	1	40				
				4	2	30				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceed three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
March 22nd, Saturday - -	12.20 a.m.–1.40 a.m.	1	20	6	—	20	0·06	Midnight–12.30 a.m.	703,300	
				5	—	45				
				4	1	0				
March 23rd, Sunday -	10.0 p.m.–10.30 p.m.	—	30	4	—	20	0·04	9.0 p.m.–10.0 p.m.	928,200	
March 24th, Monday - -	9.30 p.m.–midnight.	2	30	4	1	45	0·36	2.0 p.m.–10.0 p.m.	1,080,900	
March 25th, Tuesday - -	1.0 a.m.–5.30. a.m.	4	30	8	1	15	0·11	12.30 a.m.–2.0 a.m.	952,280	
				6	2	—				
				5	2	15				
				4	3	—				
March 26th, Wednesday -	7.30 p.m.–midnight.	4	30	4	1	30	0·08	6.0 p.m.–11.0 p.m.	1'2050'60	
March 27th, Thursday - -	Midnight–1.0 a.m.; 2.0 a.m.–8.30 a.m.	7	30	6	1	30	0·06	1.0 a.m.–7.0 a.m.	1,255,600	
				5	3	15				
				4	4	—				
March 31st, Monday - -	2.30 a.m.–7.0 a.m.; 9·45 p.m.–midnight.	6	45	7	1	30	0·18	Midnight–5.30 a.m.; 8.0 p.m.–midnight.	1,135,700	
				6	2	—				
				5	2	30				
				4	4	—				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
April 1st, Tuesday - - -	Midnight–1.30 a.m.; 2.30 a.m.–4.30 a.m.; 7.0 a.m.–7.30 a.m.; 8.30 a.m.–9.0 a.m.	4	30	7	1	—	0·09	Midnight–3.0 a.m.; 7.0 a.m.–11.0 a.m.	1,168,280	
				6	1	—				
				5	1	45				
				4	2	30				
April 4th, Friday - - -	2.50 a m.–6.0 a.m.	3	10	6	1	25	0·09	2.0 a.m.–5.0 a.m.	1,041,500	
				5	2	30				
				4	3	—				
April 5th, Saturday	6.0 a.m.–9.40 a.m.; 4.40 p.m.–7.20 p.m.	6	20	6	—	25	0·56	5.0 a.m.–7.0 p.m.	1,419,500	
				5	1	35				
				4	3	—				
April 12th, Saturday - -	11.30 p.m.–midnight.	—	30	7	—	20	0·08	10.30 p.m.–11.0 p.m.	895,500	
				6	—	30				
				5	—	30				
				4	—	30				
April 13th, Sunday - -	Midnight–1.15 a.m.	1	15	6	—	30	—	Due to rainfall on 12th.	705,500	
				5	—	45				
				4	—	50				
April 15th, Tuesday - -	1.15 p.m.–3.40 p.m.; 9.0 p.m.–10.30 p.m.	3	55	—	—	—	0·49	11.30 a.m.–10.0 p.m.	1,332,080	
April 20th, Sunday - - -	6.10 p.m.–8.20 p.m.	2	10	6	—	15	0·24	5.0 p.m.–7.0 p.m.	777,600	
				5	—	55				
				4	1	40				
April 22nd, Tuesday - -	Midnight–3.10 a.m.	3	10	6	1	—	0·20—0·05 0·15	Midnight–2.0 a.m.; 8.30 a.m.–2.0 p.m.	1,188,080	
				5	2	10				
				4	2	55				
April 30th, Wednesday - -	7.0 a.m.–7.45 a.m.; 10.45 p.m.–11.35 p.m.	1	40	5	—	30	0·20—0·10 0·10	6.0 a.m.–11.0 a.m.; 8.0 p.m.–midnight.	1,078,700	
				4	—	45				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
May 3rd, Saturday	9.40 a.m.–10.20 a.m.; 3.30 p.m.–5.0 p m.	1	50	—	—	—	0·35—0·16 0·19	7.0 a.m.–noon.; 3.0 p.m.–3.30 p.m.	1,249,200	
May 4th, Sunday	2.0 a.m.–6.15 a.m.	4	15	8 6 5 4	1 2 3 3	— 50 — 10	0·15	2.0 a.m.–4.30 a.m.	1,030,700	
May 5th, Monday	2.40 a.m.–3.40 a.m.; 7.0 a.m.–7.45 a.m.; 8.30 a.m.–9.0 a.m.	2	15	6 5 4	— 1 1	20 10 30	0·14	Midnight–3.0 a.m.; 6.30 a.m.–9.0 a.m.; 10.0 p.m.–midnight.	889,000	
May 6th, Tuesday	Midnight–1.15 a.m.; 6.20 p.m.–7.0 p.m.	1	55	5 4	— 1	30 —	0·12	5.30 p.m.–8 p.m.	1,056,880	
May 7th, Wednesday	2.30 p m.–3.0 p.m.	—	30	—	—	—	—	—	985,000	
May 9th, Friday	9.30 p.m.–10.20 a.m.	—	50	—	—	—	0·10	Noon–9.0 p.m.	1,033,000	
May 15th, Thursday	7.10 p.m.–midnight.	4	50	5 4	1 4	30 —	0·62—0·07 0·55	5 a.m.–noon; 4.0 p.m.–11 p.m.	1,487,200	
May 16th, Friday	Midnight–2.30 a.m.; 2.50 p.m.–4.10 p.m.	3	50	5 4	— 1	30 —	0·25	1.0 p.m.–7 p.m.	1,288,600	
May 17th Saturday	7.15 p.m.–midnight.	4	45	6 5 4	1 3 4	50 40 35	0·68	6.30 p.m.–midnight.	1,465,500	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
May 18th, Sunday - - -	Midnight–8.30 a.m.; 6.30 p.m.–7.30 p.m.	9	30	6 5 4	1 3 6	10 — 30	0·08	4.0 p.m.–6 p.m.	1,186,000	
May 19th, Monday - -	10.20 p.m.–11.30 p.m.	1	10	4	—	30	0·09	8.0 p.m.–11.0 p.m.	1,092,000	
May 20th, Tuesday - -	Midnight–1.30 a.m.	1	30	5 4	— 1	40 —	—	Due to rainfall on 19th.	877,180	
May 22nd, Thursday - -	1.40 p.m.–2.45 p.m.; 4.0 p.m.–midnight.	9	5	6 5 4	— 2 3	30 30 45	0·46—0·11 0·35	1·0 p.m.–2.30 p.m.; 3.30 p.m.–midnight.	1,677,300	
May 23rd, Friday - - -	Midnight–9.0 a.m.	9	—	7 6 5 4	5 6 7 8	— — 30 15	0·08	Midnight–7.0 a.m.	1,747,200	Total volume delivered at outfall=3 times average dry weather discharge.
May 25th, Sunday - -	1.35 a.m.–3.40 a.m.	2	5	6 5 4	— 1 1	40 — 10	0·03	1.30 a.m.–2.0 a.m.	856,200	
May 28th, Wednesday -	8.30 a.m.–9 a.m.	—	30	—	—	—	0·16	9.0 a.m.–10.30 a.m.	985,100	
May 29th, Thursday - -	11.30 p.m.–midnight	—	30	6 5 4	— — —	10 25 30	0·13	10.30 p.m.–midnight	834,500	
May 30th, Friday - - -	Midnight–12.30 a.m.; 2.0 a.m.–4.0 a.m; 10.0 p.m.–10.30 p.m.	3	—	7 6 5 4	1 1 1 1	— 15 30 50	0·12—0·09 0·03	1.0 a.m.–3.0 a.m.; 9.30 p.m.–10.0 p.m.	838,800	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
June 1st, Sunday - - -	3.40 a.m.–4.20 a.m.	—	40	6 5 4	— — —	15 20 35	0·04	3.0 a.m.–3.30 a.m.	692,500	
June 6th, Friday - - -	8.0 p.m.–9.20 p.m.	1	20	4	—	40	0·22—0·15 0·07	7.30 p.m.–8.0 p.m.; midnight–noon	1,007,000	
June 7th, Saturday - -	3.0 a.m.–3.50 a.m.; 3.40 p.m.–4.30 p.m.; 5.30 p.m.–9.35 p.m.	5	45	4	1	45	0·25	8.0 a.m.–7.0 p.m.	1,299,700	
June 11th, Wednesday - -	10.20 p.m.–10.40 p.m.	—	20	—	—	—	—	—	799,600	
June 12th, Thursday - -	10.20 p.m.–10.40 p.m.	—	20	—	—	—	0·01	9.0 p.m.	823,600	
June 14th, Saturday - -	1.0 p.m.–1.30 p.m.; 10.0 p.m.–10.30 p.m.	1	—	—	—	—	0·25	6.30 a.m.–1.0 p.m.	836,700	
June 17th, Tuesday - -	4.0 a.m.–7.15 a.m.	3	15	6 5 4	1 2 3	15 15 —	0·13	2.30 a.m.–6.0 a.m.	932,780	
June 18th, Wednesday - -	9.15 p.m.–9.40 p.m.	—	25	—	—	—	—	—	808,200	
June 20th, Friday - - -	9.0 a.m.–10.15 a.m.; noon–2.0 p.m.; 2.30 p.m.–3.35 p.m.; 9.0 p.m.–9.20 p.m.	4	40	4	—	45	0·32—0·31 0·01	7.0 a.m.–3.30 p.m.; 8.0 p.m.	1,358,500	
June 22nd, Sunday - -	5.0 p.m.–5.40 p.m.	—	40	4	—	30	0·02	5.0 p.m.	432,450	
June 28th, Saturday - -	9.30 p.m.–10 p.m.	—	30	—	—	—	—	—	699,000	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
July 1st, Tuesday - - -	2.30 p.m.–3.15 p.m.	—	45	6 5 4	— — —	10 15 20	0·10	1.0 p.m.–2.0 p.m.	830,080	Storm water samples taken : 3 times the D.W.F. ... 2.45 p.m. 4 " " " ... 3.0 p.m. 6 " " " ... 3.15 p.m. 3 " " " ... 4.0 p.m.
July 2nd, Wednesday - -	9.0 p.m.–9.30 p.m.	—	30	—	—	—	—	—	811,000	
July 4th, Friday - - -	8.10 a.m.–9.0 a.m.	—	50	4	—	20	0·06	2.0 a.m.–8.0 am.	868,100	
July 5th, Saturday - - -	9.30 p.m.–10.0 p.m.	—	30	4	—	20	0·02	8.0 p.m.	821,300	
July 10th, Thursday - -	Noon–2.30 p.m.; 6.0 p.m. 6.45 p.m.; 9.0 p.m.–9.50 p.m.	2	5	5 4	— —	10 20	0·50—0·42 0·07 0·01	5.0 a.m.–3.0 p.m. ; 5.0 p.m.–5.15 p.m. ; 8.0 p.m.	1,158,800	Storm water samples taken : 5 times the D.W.F. ... noon 4 " " " ... 1.15 p.m. 3 " " " ... 2.30 p.m.
July 19th, Saturday - -	8.30 p.m.–9.0 p.m.	—	30	—	—	—	—	—	707,700	
July 21st Monday - -	2.0 a.m.–4.20 a.m.	2	20	8 6 5 4	— 1 1 2	30 30 45 -	0·10	2.30 a.m.–4.15 a.m.	873,800	
July 22nd Tuesday - -	7.0 a.m.–9.0 a.m. ; 8.30 p.m.–9.30 p.m. ; 11.30 p.m.–midnight	3	30	4	—	50	0·30—0·06 0·05 0·19	6.30 a.m.–9.0 a.m. ; 10.30 a.m.–noon ; 5.0 p.m.–9.30 p.m.	1,319,080	
July 23rd, Wednesday - -	Midnight–2.15 a.m.	2	15	6 5 4	— 1 1	30 — 50	0·09	Midnight–2.0 a.m.	888,400	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
July 26th, Saturday - -	3.15 a.m.–8 a.m.	4	45	8	—	30	0·27	2.0 a.m.–6.30 a.m.	1,242,500	
				5	4	—				
				6	4	—				
				4	4	15				
July 27th Sunday - -	Midnight–9.0 a.m.	9	—	8	1	—	—	—	1,196,900	
				6	4	30				
				5	5	45				
				4	5	30				
July 28th, Monday - -	2.10 a.m.–3.30 a.m.	1	20	8	—	20	—	—	972,100	
				6	—	30				
				5	1	—				
				4	1	10				
July 29th, Tuesday - -	11.30 p.m.–midnight.	—	30	6	—	30	—	—	1,009,080	
				5	—	30				
				4	—	30				
July 30th, Wednesday -	Midnight–1.0 a.m.	1	—		—	30	—	—	854,000	
				4	—	45				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
August 2nd, Saturday	3.30 p.m.–5.45 p.m.	2	15	4	1	15	0·20	2.30 p.m.–4.15 p.m.	1,011,300	
August 3rd, Sunday	1.15 a.m.–9.45 a.m. 10.45 a.m.–11.45 a.m. 11.15 p.m.–midnight.	10	15	9 8 6 5 4	1 3 6 6 7	— — — 30 30	0·32–0·22 0·05 0·05	12.30 a.m.–6 a.m.; 10 a.m.–11 a.m.; 11 p.m.–midnight.	1,363,000	Total volume delivered at outfall = three times average dry weather discharge.
August 4th, Monday	Midnight–1.20 a.m.	1	20	6 5 4	— — 1	30 50 10	—	Due to rainfall on 3rd.	915,300	
August 7th, Thursday	2.45 a.m.–4 a.m.	1	15	8 6 5 4	— — — 1	30 35 45 —	0·03	—	878,100	
August 8th, Friday	5.30 a.m.–9.20 a.m.	3	50	6 5 4	1 2 3	30 — —	0·12	4 a.m.–9.30 a.m.	1,074,500	
August 10th, Sunday	3.0 a.m.–9.30 a.m.	6	30	6 5 4	3 4 4	20 — 30	0·10	3 a.m.–7.30 a.m.	836,670	
August 12th, Tuesday	12.30 a.m.–3.30 a.m. 5.0 a.m.–6.30 a.m.	4	30	8 6 5 4	1 2 2 4	— 30 30 —	0·12	Midnight–5.30 a.m.	1,091,880	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall : Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
August 17th, Sunday - -	3.30 p.m.–6.10 p.m.; 6.40 p.m.–7.10 p.m.; 8.20 p.m.–11.30 p.m.	6	20	8	1	—	0·46–0·16	3.0 p.m.–5.0 p.m.;	1,111,700	
				6	2	—	0·02	5 p.m.–6.0 p.m.;		
				5	4	—	0·28	8.0 p.m.–10.0 p.m.		
				4	5	30				
August 19th, Tuesday - -	5.30 a.m.–7.0 a.m.	2	30	9	—	30	0·12	6.0 a.m.–7.0 a.m.	1,002,580	
				6	1	30				
				5	1	40				
				4	2	10				
August 23rd, Saturday - -	Midnight–8.30 a.m.	8	30	8	—	30	0·29–0·08	10 p.m.–midnight on 22nd.	1,271,200	
				6	4	15		Midnight–7.30 a.m.		
				5	6	30				
				4	7	15				
August 27th, Wednesday -	12.45 p.m.–2.0 p.m.	1	15	—	—	—	0·10	12.30 p.m.–1.30 p.m.	886,900	
August 29th, Friday - -	9.30 p.m.–10.45 p.m.	1	15	—	—	—	0·08	9 p.m.–midnight.	854,100	
August 30th, Saturday - -	Midnight–1.0 a.m.	1	—	4	—	10	0·01	12.30 a.m.	731,800	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
September 2nd, Tuesday	8.0 p.m.–9.0 p.m.	1	—	—	—	—	0·11	8.15 p.m.–8.30 p.m.	869,280	
September 10th, Wednesday	6.20 a.m.–8 a.m.; 1.30 p.m.–4 p.m.; 8.0 p.m.–9.20 p.m.	5	30	5 4	— 1	30 20	0·28—0·06 0·17 0·05	6 a.m.–7.30 a.m.; 12.30 p.m.–5 p.m.; 7.30 p.m.–8.30 p.m.	1,282,000	
September 11th, Thursday	Midnight–1.30 a.m.	1	30	6 5 4	1 1 1	— 5 20	0·05	Midnight–12.45 a.m.	841,000	
September 14th, Sunday	4 a.m.–8.40 a.m.	4	40	9 8 6 5 4	— 1 2 3 4	30 20 45 30 —	—	—	838,800	
September 17th, Wednesday	2 45 a.m.–4.20 a.m.; 6.0 a.m.–7.0 a.m.; 8.20 a.m.–9.45 a.m.	5	—	6 5 4	1 1 2	15 35 30	—	—	1,055,000	
September 23rd, Tuesday	2.45 a.m.–3.30 a.m.; 4.45 a.m.–5.30 a.m.	1	30	6 5 4	— — 1	20 30 10	0·10—0·06	4.0 p.m.–5.0 p.m.	884,680	
September 27th, Saturday	9.20 p.m.–10.0 p.m.	—	40	4	—	30	None recorded.	—	661,900	

Macclesfield Storm Water Record—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
October 9th, Thursday - -	4.10 p.m.-4.50 p.m.; 7.20 p.m.-10.40 p.m.; 11.30 p.m.-midnight.	4	30	5 4	— 2	20 30	Rain gauge deranged by accident.	—	1,135,700	
October 10th, Friday - -	8.45 a.m.-9.30 a.m.	—	45	—	—		Do. do.	—	1,015,600	
October 12th, Sunday - -	9.30 p.m.—midnight.	2	30	8 6 5 4	— 2 2 2	30 10 15 15	Do. do.	—	716,450	
October 13th, Monday - -	Midnight-1.30 a.m.; 2.30 a.m.-3.30 a.m.; 5.30 a.m.-7.0 a.m.; 2 p.m.-2.30 p.m.; 4.30 p.m.-5.30 p.m.; 6.30 p.m.-7.30 p.m.; 9.0 p.m.-midnight	9	—	8 6 5 4	— 1 3 4	30 45 15 —	Do do.	—	1,791,000	
October 14th, Tuesday - -	Midnight-9.0 a.m.	9	—	9 6 5 4	2 5 7 7	— 30 — 40	Do. do.	—	1,954,680	Total volume delivered at outfall = 3 times average dry-weather discharge.
October 16th, Thursday - -	1 a.m.-8.30 a.m.; 6.30 p.m.-7.30 p.m.	8	30	9 6 5 4	1 5 6 6	30 30 30 45	0·08—0·08	6.30 p.m.-9.0 p.m.	1,596,300	
October 17th, Friday - -	2.45 a.m.-10.0 a.m; 11.30 p.m.-midnight	7	45	7 6 5 4	— 2 4 5	30 30 45 40	0·34—0·23	6.0 a.m.-11·0 a.m.	1,520,850	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
October 18th, Saturday - -	Midnight–7.30 a.m.	7	30	7	1	10	0·11—0·03	Midnight–1.0 a.m.;	1,203,200	
				6	2	20	0·08	2.0 a.m.–4.30 a.m.		
				5	4	45				
				4	6	—				
October 20th, Monday - -	3.0 a.m.–8.0 a.m.	5	—	9	1	30	0·30—0·27	3.30 a.m.–6.30 a.m.	1,303,900	
				6	3	30				
				5	3	50				
				4	4	10				
October 21st, Tuesday - -	1.30 a.m.–2.30 a.m.; 3.30 a.m.–5.15 a.m.; 5.40 a.m.–7.40 a.m.	4	45	6	1	10	0·01	6.30 p.m.	1,142,280	
				5	2	—				
				4	3	—				
October 22nd, Wednesday -	4.15 a.m.–6.20 a.m.; 7.0 a.m.–9.0 a.m.	5	5	9	—	45	0·28—0·15	3.30 a.m.–4.30 a.m.;	1,478,500	
				6	1	30	0·10	6.30 a.m.–to 8.0 a.m.		
				5	2	—				
				4	2	45				
October 23rd, Thursday - -	3.20 a.m.–6 a.m.	2	40	7	—	30	0·02	4.0 a.m.–5.0 a.m.	1,081,100	
				6	—	40				
				5	—	45				
				4	1	—				
October 26th Sunday - -	5.0 a.m.–9.0 a.m.; 6.0 p.m.–7.30 p.m.	5	30	10	1	15	0·23—0·11	2.0 a.m.–3.0 a.m.;	1,164,200	
				8	3	—	0·07	4·0 a.m.–5.0 a.m.;		
				6	3	20	0·04	3.0 p.m.–3.30 p.m.		
				5	4	—				
				4	5	15				
October 30th, Thursday - -	3.45 a.m.–5.30 a.m.	1	45	6	1	15	0·05	1.0 a.m.–3.0 a.m.	716,400	
				5	1	20				
				4	1	30				

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
November 6th, Thursday -	10.20 p.m.–midnight.	1	40	5	—	30	0·08	9.30 p.m. to midnight.	873,800	
				4	1	30				
November 7th, Friday - -	Midnight–12.45 a.m.	—	45	5	—	20	0·01	5.0 a.m.	819,000	
				4	—	30				
November 8th, Saturday -	11.40 a.m.–6.10 p.m.	6	20	4	—	50	Rain gauge deranged	—	1,279,800	
November 9th, Sunday - -	2.30 p.m.–3.20 p.m.; 6.30 p.m.–6.50 p.m.	1	10	—	—	—	Rain gauge deranged	—	854,100	
November 25th, Tuesday -	3.10 a.m.–3.45 a.m.	—	35	4	—	15	0·01	2.0 a.m.	744,880	
November 28th, Friday - -	7.30 a.m.–10.0 a.m.; 3.30 p.m.–5.30 p.m.	4	30	5	—	20	0·62—0·22 0·40	5.30 a.m. to noon; 3.0 p.m. to 6.0 p.m.	1,258,200	
				4	1	—				
November 29th, Saturday -	7.0 a.m.–8.10 a.m.	1	10	6	—	10	0·04	6.30 a.m. to 7 a.m.	753,570	
				5	—	30				
				4	—	45				
November 30th, Sunday -	3.20 a.m.–4.50 a.m.	1	20	—	—	—	0·09	9.0 a.m. to noon.	618,100	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
December 1st, Monday -	4.0 p.m.-5.40 p.m.; 7.0 p.m.-11.30 p.m.	6	10	—	—	—	Rain gauge deranged.	—	1,162,000	
December 2nd, Tuesday	7.0 a.m. to 10.0 a.m.	4	—	5 4	— 1	30 —	Rain guage deranged.	—	1,275,280	
December 3rd, Wednesday	5.45 p.m.-7.20 p.m.	1	35	8 6 5 4	— — 1 1	10 45 — 15	Rain gauge deranged.	—	1,098,600	
December 15th, Monday	1.50 a.m.-4.50 a.m.	2	—	10 8 7 6 5 4	— 1 1 2 2 2	30 30 45 — — —	0·26—0·02 0·16	At midnight; 1.30 a.m.-3.0 a.m.	1,102,900	
December 16th, Tuesday	3.50 a.m.-6.40 a.m.	2	50	7 6 5 4	— 2 2 2	40 — 15 45	0·27—0·11 0.10	3.0 a.m.-6.0 a.m.; 4.0 p.m.-6.0 p.m.	1,450,280	
December 17th, Wednesday -	7.30 a.m.-8.30 a.m.; 9.20 p.m.-midnight.	3	40	7 6 5 4	— 1 2 3	30 40 40 10	0·17—0·07 0·09	7.30 a.m.-8.0 a.m.; 10.0 p.m.-midnight.	1,314,800	
December 18th, Thursday	Midnight-7·0 a.m.	7	—	7 6 5 4	— 1 2 4	30 5 10 40	0·18—0·08 0·01	Midnight-1.0 a.m.; at 7.0 a.m.	1,253,600	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall : Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
December 19th, Friday - -	5.40 a.m.–7.10 a.m.	1	30	4	—	30	0·07—0·02	At 5.0 a.m.	1,081,000	
December 21st, Sunday - -	2.30 a.m.–4.0 a.m.; 5.30 a.m.–6.10 a.m.; 7.0 a.m.–9.0 a.m.	4	10	5	—	40	0·10—0·02	1.30 a.m.–2.30 a.m.;	937,000	
				4	1	10	0·06	6.0 a.m.–noon.		
December 22nd, Monday -	2.30 a.m.–4.20 a.m.	1	50	4	—	50	0·04	Midnight–6.0 a.m.	1,017,750	
December 25th, Thursday -	11.0 p.m.–midnight.	1	—	6	—	20	0·10	9.30 p.m.–10.0 p.m.	546,000	
				5	—	45				
				4	1	—				
December 28th, Sunday -	1.30 a.m.–3.0 a.m.	1	30	9	—	20	0·20—0·09	1.0 a.m.–1.15 a.m.;	742,670	
				6	—	50	0·10	6.30 a.m.–7.0 a.m.		
				5	1	10				
				4	1	10				
December 30th, Tuesday -	1.30 a.m.–2.20 a.m.; 2.40 a.m.–9.0 a.m.	7	10	7	1	—	0·45—0·07	Midnight–12.30 a.m.;	1,731,880	
				6	3	50	0·05	2.0 a.m.–4.0 a.m.;		
				5	4	30	0·20	5.0 a.m.–7.0 a.m.;		
				4	5	30		rest distributed.		

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1903.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
January 1st, Thursday	11 p.m.-midnight.	1	—	5 4	— —	20 45	0·02	At 10.0 p.m.	889,000	
January 2nd, Friday	7.0 a.m.-9.30 a.m.; 6.50 p.m.- 7.40 p.m.	4	—	6 5 4	— 1 2	20 — —	0·19—0·12 0·07	6.0 a.m.-8.15 a.m.; 6.0 p.m.-6.30 p.m.	1,227,300	
January 3rd, Saturday	5.45 a.m.-9.0 a.m.	3	15	9 6 5 4	— 1 2 2	20 20 — 20	0·24	5 a.m.-7 a.m.	1,328,000	
January 5th, Monday	6.20 a.m.-10.40 a.m.; 11.0 p.m.-midnight.	5	20	6 5 4	1 2 4	30 15 30	0·46—0·34 0·20 0·02	5.30 a.m.-10.0 a.m.; 10.0 a.m.-1.0 p.m.; 10.0 p.m.-midnight.	1,747,200	
January 6th, Tuesday	Midnight-7.30 a.m.	7	30	6 5 4	1 2 2	30 — 40	0·02	Midnight-1.0 a.m.	1,214,280	
January 7th, Wednesday	6·30 a.m.-8.15 a.m.; 8.40 a.m.-10.30 a.m.; 3.20 p.m. midnight.	11	35	6 8 4	— 1 3	30 — 10	0·69—0·22 0.30 0·15	5.30 a.m.-7.0 a.m.; 8.0 a.m.-10.30 a.m.; 2.30 p.m.-7.0 p.m.	1,819,000	Storm water sample taken: 4½ times the D.W.F. ... 3.30 p.m. Total volumes delivered at outfall=3 times average dry weather discharge.
January 8th, Thursday	Midnight-7.30 a.m.; 9.30 p.m.-11.30 p.m.	9	30	5 4	4 8	40 —	0·07	8.0 p.m.-9.0 p.m.	1,424,000	
January 9th Friday	11 p.m.-midnight.	1	—	5 4	— —	45 50	0·08—0·06	10.30 p.m.-midnight.	1,188,000	

MACCLESFIELD STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1903.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
January 10th, Saturday - -	Midnight–5.0 a.m.; 6.10 p.m.–midnight.	10	50	6	1	45	0·21—0·18	5.30 p.m.–7.0 p.m.;	1,389,000	
				5	3	10	0·02	at 10.30 p.m.		
				4	9	40				
January 22nd, Thursday - -	6.20 p.m.–8.30 p.m.; 10.30 p.m.–11.0 p.m.	2	4	4	—	20	0·20—0·18	5.0 p.m.–7.30 p.m.;	941,400	
							0·02	at 10.0 p.m.		
January 24th, Saturday - -	7.40 a.m.–10.30 a.m.; 10.30 p.m.–11.30 p.m.	3	50	5	—	10	0·21—0·19	5.30 a.m.–noon;	1,096,500	
				4	—	45	0·02	at 10.0 p.m.		
January 27th, Tuesday - -	2.0 a.m.–4.20 a.m.; 4.40 a.m.–8.40 a.m.	6	20	8	—	35	0·33—0·06	2·0 a.m.–5.0 a.m.;	1,500,280	
				6	2	30	0·14	5.0 a.m.–6.0 a.m.;		
				5	3	—	0·13	6.0 a.m.–10.30 a.m.		
				4	4	—				

MACCLESFIELD STORM WATER RECORD—*continued.*

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1903.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
February 1st, Sunday	2.0 a.m.–3.0 a.m.; 4.20 a.m.–7.0 a.m.; 4.20 p.m.–5.10 p.m.; 8.0 p.m.–9.0 p.m.; 10.30 p.m.–midnight.	7	—	8 6 5 4	— 1 1 3	30 — 10 —	0·10—0·01 0·05 0·02 0·02	At 1.0 a.m.; 3.30 a.m.–4.0 a.m.; 4.30 a.m.–6.0 a.m.; at 4.0 p.m.	989,500	
February 2nd, Monday	Midnight–2.0 a.m.	2	—	4	—	50	0·20	All between 10.30 a.m.–2.0 p.m.	1,007,000	
February 3rd, Tuesday	3.0 a.m.–8.30 a.m.	—		6 5 4	2 3 3	— — 45	0·05—0·04	3.0 a.m.–5.0 a.m.	1,196,780	
February 6th, Friday	8.0 p.m.–8.40 p.m.	—	40	—	—		0·05	6.30 p.m.–7.30 p.m.	738,400	
February 9th, Monday	4.30 a.m.–6.30 a.m.; 7.40 a.m.–8.40 a.m.	3	—	7 6 5 4	— 1 1 1	30 20 40 45	0·14—0·08 0·06	4.0 a.m.–5.0 a.m.; 7.0 a.m.–8.30 a.m.	902,100	
February 14th, Saturday	4.20 p.m.–5.40 p.m.	1	20	—	—		0·07—0·05	4.0 p.m.–5.0 p.m.	884,700	
February 15th, Sunday	2.10 p.m.–4.40 p.m.; 5.30 p.m.–10.30 p.m.	7	20	6 5	— 2 5	35 45 —	0·24—0·05 0·06 0·13	11.0 a.m.–3.0 p.m.; 3.30 p.m.–5.0 p.m.; 6.0 p.m.–8.30 p.m.	1,138,000	
February 20th, Friday	5.30 a.m.–6 a.m.	—	3	4	—	20	0·02	At 5.0 p.m.	618,000	
February 21st, Saturday	4.50 p.m.–6.40 p.m.	1	50	4	—		0·33—0·25	—	904,400	

MACCLESFIELD STORM WATER RECORD—*continued.*

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
1903.										
February 22nd, Sunday	8.30 a.m.–11.30 a.m.; 9.40 p.m.–11.30 p.m.	4	50	6 5 4	1 2 2	15 — 30	0·23—0·05 0·10 0·08	7.30 a.m.–8.0 a.m.; 9.0 a.m.–noon; 9.0 p.m.–9.30 p.m.	1,020,000	
February 24th, Tuesday	7.30 p.m.–midnight.	4		5 4	— 2	30 20	0·34—0·16 0·18	3.0 p.m.–8.0 p.m.; 8·30 p.m.–10.0 p.m.	1,266,780	
February 25th, Wednesday	Midnight–7.30 a.m.; 9.20 a.m.–9.50 a.m.; 1.40 p.m.–2.10 p.m.; 4.40 p.m.–5.30 p.m.; 10.30 p.m.–midnight.	10	50	9 6 5 4	— 1 2 2	45 45 10 50	0·31—0·15 0·01 0·02 0·13	4.0 a.m.–6.0 a.m.; 9.0 a.m.; 1.30 p.m.–2.0 p.m.; 4.30 p.m.–5.30 p.m.	1,758,000	Total volume delivered at outfall = 3 times average dry-weather discharge.
February 26th, Thursday	Midnight–8.30 a.m.	8	30	9 6 5 4	— 1 2 5	30 50 30 45	0·12—0·05 0·07	2 0 a.m.–2.30 a.m.; 7.30 a.m.–8.0 a.m.	1,491,800	
February 27th, Friday	1.15 a.m.–7.0 a.m.	5	45	7 6 5 4	— 1 2 3	45 45 30 45	0·06	12.30 a.m.–3.30 a.m.	1,212,200	
February 28th, Saturday	6.0 p.m.–2.20 p.m.; 9.20 p.m.–9.50 p.m.	—	50	4	—	20	0·04—0·03 0·01	At 5.0 p.m.; at 8 30 p.m.	952,400	

MACCLESFIELD STORM WATER RECORD—*continued.*

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1903.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
March 1st, Sunday - - -	1.30 p.m.–4.0 p.m.	2	30	4	1	40	0·20—0·01 0·19	At 11.0 a.m.; 1.0 p.m.–2.45 p.m.	974,200	
March 2nd, Monday - -	6.0 p.m.–midnight.	6	0	5 4	— 2	40 30	0·28—0·10 0·18	10.0 a.m.–2.0 p.m.; 6.0 p.m.–midnight.	1,603,000	
March 3rd, Tuesday - -	Midnight–8.15 a.m.	8	15	9 8 6 5 4	— 2 5 7 7	30 — 45 15 30	0·16—0·03 0·10 0·03	Midnight–1.30 a.m; 3.0 a.m.–4.0 a.m.; 4.30 a.m–5.0 a.m.	1,624,880	
March 4th, Wednesday - -	12.30 p.m.–1.30 p.m.	1	—	—	—	—	0·14	Noon–12.30 p.m.	1,085,500	
March 5th, Thursday - -	2.20 a.m.–8.30 a.m.; 10.30 p.m.–11.15 p.m.	6	55	6 5 4	4 5 6	30 — —	0·08—0·06 0·02	3.0 a.m.–5.0 a.m.; at 9.0 p.m.	1,393,500	
March 7th, Saturday - -	8.20 a.m.–10.0 a.m.; 4.30 p.m.–5.10 p.m.	2	20	—	—	—	0·08	7.0 a.m.–10.0 a.m.	978,500	
March 9th, Monday - - -	6.30 a.m.–7.15 a.m.	—	45	5 4	— —	30 45	0·05—0·03	5.30 a.m.–6.0 a.m.	808,200	
March 10th, Tuesday - -	Midnight–7.30 a.m.	7	30	8 6 5 4	2 6 7 7	— — — 20	0·20	All between midnight and 9.0 a.m.	1,528,780	
March 11th, Wednesday - -	7.30 a.m.–8.20 a.m.	—	50	—	—	—	0·02	At 7.0 a.m.	1,052,800	
March 13th, Friday - - -	5.0 p.m.–9.0 p.m.; 10.15 p.m.–midnight.	5	45	6 5 4	— 1 1	30 — 30	0·30—0·20 0·10	5.0 p.m.–7.0 p.m. 7.0 p.m.–midnight	1,312,500	

MACCLESFIELD STORM WATER RECORD—*continued.*

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
1903.										
March 14th, Saturday - -	Midnight–7.30 a.m.; 6.30 p.m.–midnight.	13	—	6	5	45	0.30—0·10	Midnight–1.30 a.m.;	1,699,300	Total volume delivered at outfall=3 times the average dry weather discharge.
				5	8	15	0.05	1.30 a.m.–3.30 a.m.;		
				4	11	30	0.15	7 0 p.m.–10.30 p.m.		
March 15th, Sunday - -	Midnight–8.30 a.m.	8	30	4	—	30	0·01	At 3.30 p.m.	1,041,800	Dilution due to rainfall on previous day.
March 17th, Tuesday - -	6.30 p.m.–8.30 p.m.	2	—	—	—	—	0·16—0·15	3.0 p.m.–10.0 p.m.	1,044,080	
March 18th, Wednesday - -	1.40 a.m.–8.0 a.m.; 12.20 p.m.–2.40 p.m.; 8.40 p.m.–midnight.	12	—	8	—	30	0·15	2.0 a.m.–2.0 p.m.	1,952,500	Total volume delivered at outfall=3 times average dry weather discharge.
				6	3	20				
				5	4	—				
				4	5	30				
March 19th, Thursday - -	Midnight–7.0 a.m.	7	—	—	—	—	—	—	1,125,000	

TABLE A(2).

MACCLESFIELD SEWAGE.

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1901.											
Thursday, 25th July	275,100	1,716,624	1·64	—	8½	7	6¾	3½	—	—	—
Friday, 26th July	151,900	947,856	·04	—	—	—	—	—	—	—	—
Saturday, 27th July	100,400	626,808	·01	—	—	—	—	—	—	—	—
Sunday, 28th July	158,200	987,168	·32	—	3½	2	¾	½	—	—	—
Monday, 29th July	108,500	677,040	—	—	—	—	—	—	—	—	—
Tuesday, 30th July	114,098	711,971	—	—	—	—	—	—	—	—	—
Wednesday, 31st July	—	—	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1901—*continued.*											
Thursday, 1st August	—	—	—	—	—	—	—	—	—	—	—
Friday, 2nd August	—	—	—	—	—	—	—	—	—	—	—
Saturday, 3rd August		—	—	—	—	—	—	—	—	—	—
Sunday, 4th August	—	—	—	—		—	—	—	—	—	—
Monday, 5th August	—	—	—	—	—	—	—	—	—	—	—
Tuesday, 6th August	—	—	·13	—	—	—	—	—	—	—	—
Wednesday, 7th August	91,000	567,840	·03	—	—	—	—	—	—	—	—
Thursday, 8th August	89,600	559,104	—	—	—	—	—	—	—	—	—
Friday, 9th August	91,000	567,840	—	—	—	—	—	—	—	—	—
Saturday, 10th August	86,100	537,264	·01	—	—	—	—	—	—	—	—
Sunday, 11th August	75,950	473,928	·08	—	—	—	—	—	—	—	—
Monday, 12th August	114,100	712,050	·18	—	½	—	—	—	—	—	—
Tuesday, 13th August	103,948	648,641	·15	—	—	—	—	—	—	—	—
Wednesday, 14th August	147,000	917,250	·33	—	—	—	—	—	—	—	—

Thursday, 15th August	154,350	963,100	·02	—		—	—	—	—	—	—
Friday, 16th August	92,050	574,400	·05	—		—	—	—	—	—	—
Saturday, 17th August	93,090	580,950	·04	—	1	—	—	—	—	—	—
Sunday, 18th August	53,200	331,970	—	—	—	—	—	—	—	—	—
Monday, 19th August	100,100	624,700	—	—		—	—	—	—	—	—
Tuesday, 20th August	95,898	598,427	—	—		—	—	—	—	—	—
Wednesday, 21st August	93,450	583,128	—	—	—	—	—	—	—	—	—
Thursday, 22nd August	92,400	576,576	—	—	—	—	—	—	—	—	—
Friday, 23rd August	89,250	556,920	—	—	—	—	—	—	—	—	—
Saturday, 24th August	81,900	511,056	—	—	—	—	—	—	—	—	—
Sunday, 25th August	66,500	414,960		—	—	—	½	—	—		—
Monday, 26th August	188,300	1,174,992	0·74	—	4	1½	¾	½	¼	—	—
Tuesday, 27th August	49,346	307,918	0·02	—	—	—	—	—	—	—	—
Wednesday, 28th August	145,250	906,360	0·17	—	½	—	—	—	—	—	—
Thursday, 29th August	116,900	729,456	0·16	—	1	—	—	—	—	—	—
Friday, 30th August	103,950	648,648	0·06	—	—	—		—	—	—	—
Saturday, 31st August	126,000	786,380	0·17	—	1½	—	¼	—	—	—	

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1901—*continued.*											
Sunday, 1st September	56,350	351,650	—	—	—	—	—	—	—	—	—
Monday, 2nd September	88,550	552,600	—	—	—	—	—	—	—	—	—
Tuesday, 3rd September	121,048	613,125	—	—	—	—	—	—	—	—	—
Wednesday, 4th September	89,950	561,208	—	—	—	—	—	—	—	—	—
Thursday, 5th September	87,150	543,816	—	—	—	—	—	—	—	—	—
Friday, 6th September	84,000	524,160	—	—	—	—	—	—	—	—	—
Saturday, 7th September	75,590	471,700	—	—	—	—	—	—	—	—	—
Sunday, 8th September	100,450	626,900	0·15	—	¾	—	—	—	—	—	—
Monday, 9th September	102,900	642,096	0·03	—	—	—	—	—	—	—	—
Tuesday, 10th September	110,698	690,175	0·03	—	—	—	—	—	—	—	—
Wednesday, 11th September	129,500	808,080	0·08	—	—	—	—	—	—	—	—
Thursday, 12th September	99,750	622,440	—	—	—	—	—	—	—	—	—
Friday, 13th September	97,650	609,336	—	—	—	—	—	—	—	—	—
Saturday, 14th September	89,950	561,288	—	—	—	—	—	—	—	—	—

Sunday, 15th September -	76,300	476,112	—	—	—	—	—	—	—	—	—
Monday, 16th September -	127,050	792,792	0·10	—	—	—	—	—	—	—	—
Tuesday, 17th September -	183,748	1,146,575	0·43	—	4	2	¼	—	—	—	—
Wednesday, 18th September -	100,100	624,624	—	—	—	—	—	—	—	—	—
Thursday, 19th September -	97,650	609,336	—	—	—	—	—	—	—	—	—
Friday, 20th September -	106,400	663,936	0·10	—	¾	—	¼	—		—	—
Saturday, 21st September -	101,150	631,176	0·05	—	—	—	—	—	—	—	—
Sunday, 22nd September -	67,550	421,512	—	—	—	—	—	—	—	—	—
Monday, 23rd September -	93,450	583,128	—	—	—	—	—	—	—	—	—
Tuesday, 24th September -	96,948	604,955	—	—	—	—	—	—	—	—	—
Wednesday, 25th September -	122,850	766,584	0·07	—	1	—	—	—	—	—	—
Thursday, 26th September -	102,900	642,096	—	—	—	—	—	—	—	—	—
Friday, 27th September -	96,250	600,600	—	—	—	—	—	—	—	—	—
Saturday, 28th September -	97,300	607,152	—	—	—	—	—	—	—	—	—
Sunday, 29th September -	77,010	480,600	—	—	—	—	—	—	—	—	—
Monday, 30th September -	79,100	493,600	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1901—*continued.*											
Tuesday, 1st October	127,398	794,975	0·28	—	1	—	½	½	—	—	—
Wednesday, 2nd October	111,300	694,512	—	—	1	—	—	—	—	—	—
Thursday, 3rd October	133,350	832,104	0·23	—	2	2	—	—	—	—	—
Friday, 4th October	151,550	945,672	0·28	—	2	2	1	1	—	—	—
Saturday, 5th October	124,950	779,688	0·17	—	½	—	—	—	—	—	—
Sunday, 6th October	168,000	1,048,320	0·62	—	4	3½	2½	2½	¼	—	Storm samples taken.
Monday, 7th October	129,500	808,080	0·04	—	½	—	—	—	—	—	—
Tuesday, 8th October	255,548	1,594,675	0·65	—	6	4½	3½	3½	—	—	—
Wednesday, 9th October	269,150	1,679,496	0·36	—	3½	1	1	½	—	—	—
Thursday, 10th October	123,550	770,952	0·03	—	—	—	—	—	—	—	—
Friday, 11th October	119,000	742,560	0·03	—	—	—	—	—	—	—	—
Saturday, 12th October	115,150	718,600	0·07	—	—	—	—	—	—	—	—
Sunday, 13th October	105,350	657,500	0·11	—	¾	—	—	—	—	—	—
Monday, 14th October	114,800	716,400	—	—	—	—	—	—	—	—	—

Tuesday, 15th October	115,498	720,775	—	—	—	—	—	—	—	—	—
Wednesday, 16th October	90,650	565,656	—	—	—	—	—	—	—	—	—
Thursday, 17th October	146,300	912,912	0·18	—	½	—	¼	—	—	—	—
Friday, 18th October	128,800	803,712	0·22	—	⅓	—	¼	—	—	—	—
Saturday, 19th October	84,000	524,160	—	—	—	—	—	—	—	—	—
Sunday, 20th October	62,300	388,752	—	—	—	—	—	—	—	—	—
Monday, 21st October	94,500	589,680	—	—	—	—	—	—	—	—	—
Tuesday, 22nd October	123,858	635,675	—	—	—	—	—	—	—	—	—
Wednesday, 23rd October	114,800	716,352	0·04	—	—	—	—	—	—	—	—
Thursday, 24th October	191,100	1,192,464	0·57	—	2¾	2¾	2½	2½	½	—	—
Friday, 25th October	—	693,400	0·15	—	1	—	¼	—	—	—	—
Saturday, 26th October	—	—	—	—	—	—	—	—	—	—	—
Sunday, 27th October	—	—	—	—	—	—	—	—	—	—	—
Monday, 28th October	—	—	0·06	—	—	—	—	—	—	—	—
Tuesday, 29th October	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 30th October	85,750	535,080	—	—	—	—	—	—	—	—	—
Thursday, 31st October	83,300	519,692	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1901—*continued.*											
Friday, 1st November	85,050	530,712	—	—	—	—	—	—	—	—	—
Saturday, 2nd November	80,150	500,136	—	—	—	—	—	—	—	—	—
Sunday, 3rd November	66,500	414,960	—	—	—	—	—	—	—	—	—
Monday, 4th November	89,600	559,104	—	—	—	—	—	—	—	—	—
Tuesday, 5th November	108,498	677,027	—	—	—	—	—	—	—	—	—
Wednesday, 6th November	132,300	825,552	—	—	—	—	—	—	—		—
Thursday, 7th November	118,300	738,300	—	—	—	—	—	—	—	—	—
Friday, 8th November	117,250	731,800	—	—	—	—	—	—	—	—	—
Saturday, 9th November	113,050	705,500	—	—	—	—	—	—	—	—	—
Sunday, 10th November	119,000	742,600	0·05	—	1	—	—	—	—	—	—
Monday, 11th November	350,000	2,184,000	0·50	Total volume=three times D.W.F.	13½	10½	6	2	½	—	—
Tuesday, 12th November	311,848	1,945,981	1·55	—	13¾	8	8	5	2¾	2	Storm samples taken.
Wednesday, 13th November	183,400	1,144,500	0·03	—	—	—	—	—	—	—	—
Thursday, 14th November	128,800	803,800	—	—	—	—	—	—	—	—	—

Friday, 15th November	115,500	720,800	—	—	—	—	—	—	—	—	—
Saturday, 16th November	98,360	613,800	—	—	—	—	—	—	—	—	—
Sunday, 17th November	88,900	554,800	0·01	—	—	—	—	—	—	—	—
Monday, 18th November	185,500	1 157,500	0·29	—	1½	—	—	—	—	—	—
Tuesday, 19th November	224,698	1,402,275	0·26	—	1¾	—	—	—	—	—	—
Wednesday, 20th November	334,600	2,088,000	0·78	—	11½	9	5½	3½	—	—	—
Thursday, 21st November	291,200	1,817,300	0·44	—	2½	—	½	—	—	—	—
Friday, 22nd November	284,900	1,778,000	0·30	—	3	1½	1	1	—	—	—
Saturday, 23rd November	164,500	1,026,500	—	—	—	—	—	—	—	—	—
Sunday, 24th November	132,300	825,800	—	—	—	—	—	—	—	—	—
Monday, 25th November	151,900	948,000	—	—	—	—	—	—	—	—	—
Tuesday, 26th November	170,098	1,061,575	—	—	—	—	—	—	—	—	—
Wednesday, 27th November	117,950	736,200	0·01	—	—	—	—	—	—	—	—
Thursday, 28th November	109,550	683,700	—	—	—	—	—	—	—	—	—
Friday, 29th November	107,800	672,800	—	—	—	—	—	—	—	—	—
Saturday, 30th November	107,100	668,500	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1901—*continued.*											
Sunday, 1st December	93,800	585,400	0·01	—	—	—	—	—	—	—	—
Monday, 2nd December	112,700	703,400	0·01	—	—	—	—	—	—	—	—
Tuesday, 3rd December	129,848	810,475	—	—	—	—	—	—	—	—	—
Wednesday, 4th December	128,450	801,700	—	—	—	—	—	—	—	—	—
Thursday, 5th December	171,850	1,072,500	0·11	—	2½	1	—	—	—	—	—
Friday, 6th December	135,450	845,300	—	—	—	—	—	—	—	—	—
Saturday, 7th December	193,550	1,207,800	0·25	—	3¼	2½	2½	1	—	—	—
Sunday, 8th December	355,250	2,217,000	0·50	—	13	8	6¼	4	2¾	1	—
Monday, 9th December	303,800	1,896,000	0·24	—	5	4½	1½	1	—	—	—
Tuesday, 10th December	312,898	1,952,775	0·19	—	6	4½	—	—	—	—	—
Wednesday, 11th December	292,600	1,826,000	0·09	—	3	2	¼	—	—	—	—
Thursday, 12th December	282,800	1,760,000	0·45	—	8½	8½	4	3	—	—	—
Friday, 13th December	354,200	2,210,500	0·14	—	7	7	—	—	—	—	—
Saturday, 14th December	246,750	1,535,000	0·07	—	—	—	—	—	—	—	—

Sunday, 15th December	141,400	882,500	—	—	—	—	—	—	—	—	—
Monday, 16th December	224,700	1,402,000	0·21	—	—	—	—	—	—	—	—
Tuesday, 17th December	236,248	1,474,275	0·07	—	1½	—	½	½	—	—	—
Wednesday, 18th December	201,250	1,256,000	0·01	—	—	—	—	—	—	—	—
Thursday, 19th December	172,200	1,074,500	0·10	—	—	—	—	—	—	—	—
Friday, 20th December	163,800	1,022,000	—	—	—	—	—	—	—	—	—
Saturday, 21st December	146,650	915,200	0·02	—	—	—	—	—	—	—	—
Sunday, 22nd December	134,750	841,000	—	—	—	—	—	—	—	—	—
Monday, 23rd December	236,250	1,474,250	0·34	—	5½	5½	—	—	—	—	—
Tuesday, 24th December	324,448	2,024,775	—	—	12	12	—	—	—	—	—
Wednesday, 25th December	245,000	1,529,000	—	—	5¼	5½	½	½	—	—	—
Thursday, 26th December	261,100	1,629,300	—	—	2	½	—	—	—	—	—
Friday, 27th December	201,200	1,255,500	—	—	—	—	—	—	—	—	—
Saturday, 28th December	269,150	1,679,500	—	—	8	2½	1	½	—	—	—
Sunday, 29th December	267,750	1,670,500	—	—	—	—	—	—	—	—	—
Monday, 30th December	259,700	1,620,500	—	—	2	2	½	—	—	—	—
Tuesday, 31st December	283,148	1,766,775	0·50	—	6½	6½	6	6	2	1½	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902.											
Wednesday, 1st January -	377,700	2,356,800	0·15	—	12	11	3½	3½	½	2½	—
Thursday, 2nd January -	292,700	1,826,500	0·13	—	5½	2½	1	½	—	—	—
Friday, 3rd January - -	220,850	1,378,200	—	—	—	—	—	—	—	—	—
Saturday, 4th January -	352,450	2,199,300	—	—	12	12	7¾	4	1¼	1	—
Sunday, 5th January - -	218,070	1,360,800	0·02	—	—	—	—	—	—	—	—
Monday, 6th January - -	211,050	1,317,000	0·01	—	—	—	—	—	—	—	—
Tuesday, 7th January -	186,550	1,164,080	—	—	—	—	—	—	—	—	—
Wednesday, 8th January -	148,860	929,000	—	—	—	—	—	—	—	—	—
Thursday, 9th January -	157,870	985,200	0·01	—	—	—	—	—	—	—	—
Friday, 10th January - -	208,600	1,301,600	0·09	—	½	—	—	—	—	—	—
Saturday, 11th January -	158,900	991,700	—	—	—	—	—	—	—	—	—
Sunday, 12th January - -	131,950	823,500	—	—	—	—	—	—	—	—	—
Monday, 13th January- -	140,350	875,600	—	—	—	—	—	—	—	—	—
Tuesday, 14th January- -	159,950	998,180	—	—	—	—	—	—	—	—	—

Wednesday, 15th January -	165,670	1,033,700	—	—	—	—	—	—	—	—	—
Thursday, 16th January -	165,920	1,035,300	—	—	—	—	—	—	—	—	—
Friday, 17th January -	165,570	1,034,300	—	—	—	—	—	—	—	—	—
Saturday, 18th January -	147,000	917,500	—	—	—	—	—	—	—	—	—
Sunday, 19th January -	127,400	795,100	—	—	—	—	—	—	—	—	—
Monday, 20th January -	165,920	1,035,300	0·05	—	—	—	—	—	—	—	—
Tuesday, 21st January -	141,400	882,380	—	—	—	—	—	—	—	—	—
Wednesday, 22nd January -	147,700	921,800	—	—	—	—	—	—	—	—	—
Thursday, 23rd January -	148,400	926,200	—	—	—	—	—	—	—	—	—
Friday, 24th January -	130,560	814,800	—	Snow.	—	—	—	—	—	—	—
Saturday, 25th January -	195,300	1,218,800	0·18	Snow.	—	—	—	—	—	—	—
Sunday, 26th January -	109,900	685,900	0·10	—	—	—	—	—	—	—	—
Monday, 27th January -	237,300	1,480,700	0·24	Snow.	1	1	—	—	—	—	—
Tuesday, 28th January -	327,650	2,044,280	0·12	—	3	2	1	1	¼	—	—
Wednesday, 29th January -	186,650	1,164,600	0·01	Snow.	—	—	—	—	—	—	—
Thursday, 30th January -	171,150	1,068,000	0·02	—	—	—	—	—	—	—	—
Friday, 31st January -	161,700	1,009,000	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded $3\frac{1}{2}$ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Saturday, 1st February	163,450	1,020,000	—	—	—	—	—	—	—	—	—
Sunday, 2nd February	142,100	886,800	—	—	—	—	—	—	—	—	—
Monday, 3rd February	167,300	1,044,000	—	—	—	—	—	—	—	—	—
Tuesday, 4th February	121,450	757,880	—	—	—	—	—	—	—	—	—
Wednesday, 5th February	116,200	725,200	—	—	—	—	—	—	—	—	—
Thursday, 6th February	113,750	709,900	—	—	—	—	—	—	—	—	—
Friday, 7th February	110,700	690,900	—	—	—	—	—	—	—	—	—
Saturday, 8th February	117,950	736,200	0·06	Snow.	—	—	—	—	—	—	—
Sunday, 9th February	108,500	677,200	0·12	Snow.	—	—	—	—	—	—	—
Monday, 10th February	122,500	764,600	0·10	—	—	—	—	—	—	—	—
Tuesday, 11th February	147,350	919,680	0·12	Snow.	—	—	—	—	—	—	—
Wednesday, 12th February	144,550	902,200	0·15	—	—	—	—	—	—	—	—
Thursday, 13th February	128,800	803,900	0·01	—	—	—	—	—	—	—	—
Friday, 14th February	133,350	832,300	—	—	—	—	—	—	—	—	—

Saturday 15th February	133,350	832,300	–	—	—	—	—	—	—	—	—
Sunday, 16th February	111,650	696,900	—	—	—	—	—	—	—	—	—
Monday, 17th February	145,600	908,800	—	—	—	—	—	—	—	—	—
Tuesday, 18th February	121,450	757,980	—	—	—	—	—	—	—	—	—
Wednesday, 19th February	135,450	845,300	—	—	—	—	—	—	—	—	—
Thursday, 20th February	130,200	812,600	—	—	—	—	—	—	—	—	—
Friday, 21st February	140,000	873,800	—	—	—	—	—	—	—	—	—
Saturday, 22nd February	178,500	1,114,000	0·04	—	—	—	—	—	—	—	—
Sunday, 23rd February	136,500	852,000	0·07	—	—	—	—	—	—	—	—
Monday, 24th February	210,000	1,310,500	0·2	—	—	—	—	—	—	—	—
Tuesday, 25th February	165,550	1,033,080	—	—	—	—	—	—	—	—	—
Wednesday, 26th February	154,350	963,400	—	—	—	—	—	—	—	—	—
Thursday, 27th February	186,200	1,162,000	0·15	—	2	2	—	—	—	-	—
Friday, 28th February	168,000	1,048,300	0·04	—	¾	—	½	—	—	—	—

MACCLESFIELD SEWAGE.—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons	Inches.								
1902—*continued.*											
Saturday, 1st March	129,850	810,600	0·01	—	—	—	—	—	—	—	—
Sunday, 2nd March	114,100	712,060	0·03	—	—	—	—	—	—	—	—
Monday, 3rd March	131,250	821,300	0·01	—	—	—	—	—	—	—	—
Tuesday, 4th March	145,250	906,480	0·01	—	—	—	—	—	—	—	—
Wednesday, 5th March	117,240	731,700	0·01	—	—	—	—	—	—	—	—
Thursday, 6th March	108,500	677,100	—	—	—	—	—	—	—	—	—
Friday, 7th March	133,320	832,200	0·05	—	—	—	—	—	—	—	—
Saturday, 8th March	147,700	921,800	0·21	—	—	—	—	—	—	—	—
Sunday, 9th March	131,600	821,300	0·09	—	—	—	—	—	—	—	—
Monday, 10th March	162,730	1,015,500	0·14	—	—	—	—	—	—	—	—
Tuesday, 11th March	112,690	703,280	—	—	—	—	—	—	—	—	—
Wednesday, 12th March	127,730	797,100	—	—	—	—	—	—	—	—	—
Thursday, 13th March	146,730	915,800	0·10	—	1	1	—	—	—	—	—
Friday, 14th March	198,100	1,230,000	0·33	—	4	4	1	½	—	—	—

Saturday, 15th March	171,100	1,067,000	0·03	—	—	—	—	—	—	—	—
Sunday, 16th March	109,900	685,900	—	—	—	—	—	—		—	—
Monday, 17th March	140,330	875,900	0·02	—	—	—	—	—	—	—	—
Tuesday, 18th March	144,550	902,080	—	—	—	—	—	—	—	—	—
Wednesday, 19th March	133,700	834,400	0·14	—	—	—	—	—	—	—	—
Thursday, 20th March	162,000	1,010,900	0·19	—	1	—	—	—	—	—	—
Friday, 21st March	133,000	830,100	0·08	—	—	—	—	—	—	—	—
Saturday, 22nd March	112,700	703,300	0·06	—	½	—	—	—	—	—	—
Sunday, 23rd March	148,730	928,200	0·04	—	—	—	—	—	—	—	—
Monday, 24th March	173,230	1,080,900	0·36	—	2½	1½	—	—	—	—	—
Tuesday, 25th March	152,550	952,280	0·11	—	1½	—	—	—	—	—	—
Wednesday, 26th March	193,200	1,205,600	0·08	—	½	—	—	—	—	—	—
Thursday, 27th March	201,200	1,255,600	0·06	—	—	—	—	—	—	—	—
Friday, 28th March	130,540	814,600	0·02	—	—	—	—	—	—	—	—
Saturday, 29th March	128,080	799,350	0·03	—	—	—	—	—	—	—	—
Sunday, 30th March	112,330	701,100	0·02	—	—	—	—	—	—	—	—
Monday, 31st March	182,000	1,135,700	0·18	—	½	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Tuesday, 1st April	187,230	1,168,280	0·09	—	½	—	—	—	—	—	—
Wednesday, 2nd April	136,840	853,900	—	—	—	—	—	—	—	—	—
Thursday, 3rd April	155,050	967,600	0·10	—	—	—	—	—	—	—	—
Friday, 4th April	166,930	1,041,500	0·09	—	—	—	—	—	—	—	—
Saturday, 5th April	227,500	1,419,500	0·56	—	3½	2¼	—	—	—	—	—
Sunday, 6th April	105,000	655,250	—	—	—	—	—	—	—	—	—
Monday, 7th April	108,860	679,230	—	—	—	—	—	—	—	—	—
Tuesday, 8th April	132,650	827,780	—	—	—	—	—	—	—	—	—
Wednesday, 9th April	142,100	886,800	—	—	—	—	—	—	—	—	—
Thursday, 10th April	130,900	816,900	—	—	—	—	—	—	—	—	—
Friday, 11th April	131,950	823,400	—	—	—	—	—	—	—	—	—
Saturday, 12th April	143,500	895,500	0·08	—	½	—	¼	—	—	—	—
Sunday, 13th April	113,050	705,500	0·01	—	—	—	—	—	—	—	—
Monday, 14th April	131,270	819,050	0·01	—	—	—	—	—	—	—	—

Tuesday, 15th April	213,500	1,332,080	0·49	—	3½	3	1		—	—	—
Wednesday, 16th April	122,500	764,500	0·02	—	—	—	—	—	—	—	—
Thursday, 17th April	130,900	816,850	—	—	—	—	—	—	—	—	—
Friday, 18th April	123,200	768,900	—	—	—	—	—	—	—	—	—
Saturday, 19th April	110,600	690,200	—	—	—	—	—	—	—	—	—
Sunday, 20th April	124,600	777,600	0·24	—	½	—	—	—	—	—	—
Monday, 21st April	131,250	819,000	0·08	—	—	—	—	—	—	—	—
Tuesday, 22nd April	190,400	1,188,080	0·20	—	—	—	—	—	—	—	—
Wednesday, 23rd April	143,170	893,400	—	—	—	—	—	—	—	—	—
Thursday, 24th April	133,000	830,000	0·02	—	—	—	—	—	—	—	—
Friday, 25th April	129,500	808,100	—	—	—	—	—	—	—		—
Saturday, 26th April	110,950	692,400	—	—	—	—	—	—	—	—	—
Sunday, 27th April	94,150	587,450	—	—	—	—	—	—	—	—	—
Monday, 28th April	128,100	799,500	—	—	—	—	—	—	—	—	—
Tuesday, 29th April	116,200	725,080	—	—	—	—	—	—	—	—	—
Wednesday, 30th April	172,900	1,078,700	0·20	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE, 1902—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Thursday, 1st May - -	127,750	797,300	0·03	—	—	—	—	—	—	—	—
Friday, 2nd May - - -	131,950	823,400	0·16	—	—	—	—	—	—	—	—
Saturday, 3rd May - -	200,200	1,249,200	0·35	—	2	—	—	—	—	—	—
Sunday, 4th May - - -	165,200	1,030,700	0·15	—	1	—	—	—	—	—	—
Monday, 5th May - -	142,460	889,000	0·14	—	—	—	—	—	—	—	—
Tuesday, 6th May - -	169,400	1,056,880	0·12	—	1½	—	½	—	—	—	—
Wednesday, 7th March -	157,860	985,000	—	—	¾	—	¼	—	—	—	—
Thursday, 8th May - -	127,750	797,200	—	—	—	—	—	—	—	—	—
Friday, 9th May - - -	165,550	1,033,000	0·10	—	½	—	—	—	—	—	—
Saturday, 10th May - -	110,600	690,200	—	—	—	—	—	—	—	—	—
Sunday, 11th May - -	96,600	602,800	—	—	—	—	—	—	—	—	—
Monday, 12th May - -	126,350	788,400	—	—	—	—	—	—	—	—	—
Tuesday, 13th May - -	123,200	768,780	0·03	—	—	—	—	—	—	—	—
Wednesday, 14th May - -	123,200	768,800	—	—	—	—	—	—	—	—	—

Thursday, 15th May - -	238,350	1,487,200	0·62	—	4	2¾	—	—	—	--	—
Friday, 16th May - - -	206,500	1,288,600	0·25	—	2	2	—	—	—	—	—
Saturday, 17th May - -	234,850	1,465,500	0·68	—	3¾	3	¼	—	—	—	—
Sunday, 18th May - -	190,050	1,186,000	0·08	—	½	—	—	—	—	—	—
Monday, 19th May - -	175,000	1,092,000	0·09	—	—	—	—	—	—	—	—
Tuesday, 20th May - -	138,950	877,180	—	—	—	—	—	—	—	—	—
Wednesday, 21st May - -	153,650	959,000	—	—	—	—	—	—	—	—	—
Thursday, 22nd May - -	268,800	1,677,300	0·46	—	9	9	3½	1½	—	—	—
Friday, 23rd May - - -	280,000	1,747,200	0·08	—	2	1½	—	—	—	—	—
Saturday, 24th May - -	165,550	1,033,000	0·01	—	—	—	—	—	—	—	—
Sunday, 25th May - -	137,200	856,200	0·03	—	—	—	—	—	—	—	—
Monday, 26th May - -	144,900	904,300	—	—	—	—	—	—	—	—	—
Tuesday, 27th May - -	175,700	1,096,280	0·01	—	—	—	—	—	—	—	—
Wednesday, 28th May - -	157,850	985,100	0·16	—	½	—	—	—		—	—
Thursday, 29th May - -	133,700	834,500	0·13	—	½	—	—	—	—	—	—
Friday, 30th May - - -	134,400	838,800	0·12	—	½	—	—	—	—	—	—
Saturday, 31st May - -	131,600	821,300	0·01	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Sunday, 1st June -	110,950	692,500	0·04	—	—	—	—	—	—	—	—
Monday, 2nd June	102,900	642,250	0·02	—	—	—	—	—	—	—	—
Tuesday, 3rd June	125,300	781,980	—	—	—	—	—	—	—	—	—
Wednesday, 4th June	117,600	734,000	—	—	—	—	—	—	—	—	—
Thursday, 5th June	156,470	976,600	0·01	—	—	—	—	—	—	—	—
Friday, 6th June -	161,350	1,007,000	0·22	—	¾	—	½	½	—	—	—
Saturday, 7th June	208,270	1,299,700	0·25	—	2½	1	—	—	—	—	—
Sunday, 8th June -	102,900	642,250	—	—	—	—	—	—	—	—	—
Monday, 9th June	124,250	775,500	—	—	—	—	—	—	—	—	—
Tuesday, 10th June	116,550	727,380	—	—	—	—	—	—	—	—	—
Wednesday, 11th June -	128,100	799,600	—	—	—	—	—	—	—	—	—
Thursday, 12th June	131,950	823,600	0·01	—	—	—	—	—	—	—	—
Friday, 13th June	88,200	550,450	0·01	—	—	—	—	—	—	—	—
Saturday, 14th June	134,050	836,700	0·25	—	¾	—	—	—	—	—	—

Sunday, 15th June	98,350	613,700	—	—	—	—	—	—	—	—	—
Monday, 16th June	121,450	758,000	—	—	—	—	—	—	—	—	—
Tuesday, 17th June	149,450	932,780	0·13	—	—	—	—	—	—	—	—
Wednesday, 18th June	129,500	808,200	—	—	—	—	—	—	—	—	—
Thursday, 19th June	124,700	778,250	—	—	—	—	—	—	—	—	—
Friday, 20th June	217,700	1,358,500	0·32	—	4	2½	1	1	—	—	—
Saturday, 21st June	121,800	760,200	—	—	—	—	—	—	—	—	—
Sunday, 22nd June	69,300	432,450	0·02	—	—	—	—	—	—	—	—
Monday, 23rd June	98,000	611,500	—	—	—	—	—	—	—	—	—
Tuesday, 24th June	137,900	860,680	—	—	—	—	—	—	—	—	—
Wednesday, 25th June	113,750	710,000	—	—	—	—	—	—	—	—	—
Thursday, 26th June	135,000	842,600	—	—	—	—	—	—	—	—	—
Friday, 27th June	112,000	699,000	—	—	—	—	—	—	—	—	—
Saturday, 28th June	112,000	699,000	—	—	—	—	—	—	—	—	—
Sunday, 29th June	63,350	395,300	—	—	—	—	—	—	—	—	—
Monday, 30th June	89,600	559,150	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Tuesday, 1st July - -	133,000	830,080	0·10	—	1	1	½	—	—	—	—
Wednesday, 2nd July - -	129,500	811,000	—	—	—	—	—	—	—	—	—
Thursday, 3rd July - -	121,100	755,800	—	—	—	—	—	—	—	—	—
Friday, 4th July - - -	138,600	865,100	0·06	—	—	—	—	—	—	—	—
Saturday, 5th July - -	131,600	821,300	0·02	—	—	—	—	—	—	—	—
Sunday, 6th July - - -	95,200	594,050	0·02	—	—	—	—	—	—	—	—
Monday, 7th July - -	135,450	845,300	—	—	—	—	—	—	—	—	—
Tuesday, 8th July - -	140,000	867,480	0·08	—	—	—	—	—	—	—	—
Wednesday, 9th July - -	170,450	1,063,600	0·22	—	—	—	—	—	—	—	—
Thursday, 10th July - -	203,700	1,158,800	0·50	—	2½	2	1½	1	—	—	—
Friday, 11th July - -	119,700	747,000	—	—	—	—	—	—	—	—	—
Saturday, 12th July - -	101,850	635,600	—	—	—	—	—	—	—	—	—
Sunday, 13th July - -	85,750	535,100	—	—	—	—	—	—	—	—	—
Monday, 14th July - -	122,150	762,150	—	—	—	—	—	—	—	—	—

Tuesday 15th July	123,900	773,230	—	—	—		—	—	—	—	—
Wednesday, 16th July	119,000	742,600	—	—	—	—	—	—	—	—	—
Thursday. 17th July	122,850	766,700	—	—	—	—	—	—	—	—	—
Friday, 18th July	124,950	779,800	—	—	—	—	—	—	—	—	—
Saturday, 19th July	113,400	707,700	—	—	—	—	—	—	—	—	—
Sunday, 20th July	89,950	561,300	—	—	—	—	—	—	—	—	—
Monday, 21st July	140,000	873,800	0.10	—	½	—	—	—	—	—	—
Tuesday, 22nd July	211,400	1,319,080	0·30	—	3	1½	—	—	—	—	—
Wednesday, 23rd July	137,560	858,400	0·09	—	—	—	—	—	—	—	—
Thursday, 24th July	119,700	747,000	0·02	—	—	—	—	—	—	—	—
Friday, 25th July	109,550	683,650	—	—	—	—	—	—	—	—	—
Saturday, 26th July	199,150	1,242,500	0·27	Clock stopped Saturday 8 p.m. Total for week 0·90.	1	—	—	—	—	—	—
Sunday, 27th July	191,800	1,196,900	—		2	2	½	—	—	—	—
Monday, 28th July	155,750	972,100	—		½	—	—	—	—	—	—
Tuesday, 29th July	161,700	1,009,080	—		½	—	¼	—	—	—	—
Wednesday, 30th July	136,850	854,000	—		½	—	—	—	—	—	—
Thursday, 31st July	118,650	740,000	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Friday, 1st August	130,200	812,600	—	—	—	—	—	—	—	—	—
Saturday, 2nd August	162,050	1,011,300	0·20	—	1¾	1	1	¾	—	—	—
Sunday, 3rd August	218,400	1,363,000	0·32	—	3½	1	¾	—	—	—	—
Monday, 4th August	146,650	915,300	—	—	—	—	—	—	—	—	—
Tuesday, 5th August	161,350	1,006,980	—	—	—	—	—	—	—	—	—
Wednesday, 6th August	150,500	939,200	0·05	—	—	—	—	—	—	—	—
Thursday, 7th August	140,700	878,100	0·03	—	½	—	—	—	—	—	—
Friday, 8th August	172,200	1,074,500	0·12	—	½	—	—	—	—	—	—
Saturday, 9th August	134,050	836,670	0·01	—	—	—	—	—	—	—	—
Sunday, 10th August	173,600	1,083,300	0·10	—	—	—	—	—	—	—	—
Monday, 11th August	113,400	707,700	0·04	—	—	—	—	—	—	—	—
Tuesday, 12th August	175,000	1,091,880	0·12	—	1	1	—	—	—	—	—
Wednesday, 13th August	153,300	956,800	0·09	—	½	—	—	—	—	—	—
Thursday, 14th August	116,900	729,600	—	—	—	—	—	—	—	—	—

Friday, 15th August	116,900	729,600	—	—	—	—	—	—	—	—	—
Saturday, 16th August	105,000	655,300	0·02	—	—	—	—	—	—	—	—
Sunday, 17th August	178,150	1,111,700	0·46	—	3¾	2	2	1½	½	—	—
Monday, 18th August	145,250	906,500	0·01	—	—	—	—	—	—	—	—
Tuesday, 19th August	160,650	1,002,580	0·12	—	1½	1½	½	—	—	—	—
Wednesday, 20th August	122,850	766,700	0·04	—	—	—	—	—	—	—	—
Thursday, 21st August	107,800	672,800	—	—	—	—	—	—	—	—	—
Friday, 22nd August	122,500	764,560	0·08	—	—	—	—	—	—	—	—
Saturday, 23rd August	203,700	1,271,200	0·29	—	1	—	—	—	—	—	—
Sunday, 24th August	121,450	758,000	—	—	—	—	—	—	—	—	—
Monday, 25th August	127,750	797,400	—	—	—	—	—	—	—	—	—
Tuesday, 26th August	126,350	788,580	—	—	—	—	—	—	—	—	—
Wednesday, 27th August	142,100	886,900	0·10	—	1	1	¾	—	—	—	—
Thursday, 28th August	114,100	712,130	—	—	—	—	—	—	—	—	—
Friday, 29th August	136,850	854,100	0·08	—	—	—	—	—	—	—	—
Saturday, 30th August	117,250	731,800	0·01	—	—	—	—	—	—	—	—
Sunday, 31st August	128,450	801,700	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Monday, 1st September	116,500	727,400	—	—	—	—	—	—	—	—	—
Tuesday, 2nd September	139,300	869,280	0·10	—	¾	—	—	—	—	—	—
Wednesday, 3rd September	155,050	967,750	0·04	—	—	—	—	—	—	—	—
Thursday, 4th September	139,650	871,550	—	—	—	—	—	—	—	—	—
Friday, 5th September	122,500	764,570	0·01	—	—	—	—	—	—	—	—
Saturday, 6th September	130,200	812,630	0·02	—	—	—	—	—	—	—	—
Sunday, 7th September	94,140	587,500	0·01	—	—	—	—	—	—	—	—
Monday, 8th September	134,050	836,700	0·02	—	—	—	—	—	—	—	—
Tuesday, 9th September	130,190	802,780	0·02	—	—	—	—	—	—	—	—
Wednesday, 10th September	205,450	1,282,000	0·28	—	3¼	2	¾	¾	—	—	—
Thursday, 11th September	134,750	841,000	0·05	Clock gauge out of order. Total for this week 0·18 inches.	½	—	—	—	—	—	—
Friday, 12th September	141,750	884,700	—		½	—	¼	—	—	—	—
Saturday, 13th September	98,000	611,500	—		—	—	—	—	—	—	—
Sunday, 14th September	134,400	838,800	—		½	—	—	—	—	—	—

Monday, 15th September	115,150	718,600	—		—		—	—	—	—	—
Tuesday, 16th September	126,350	788,580	—		½	—	—	—	—	—	—
Wednesday, 17th September	169,050	1,055,000	—		1½	1½	½	—	—	—	—
Thursday, 18th September	135,100	843,200	—	—	—	—	—	—	—	—	—
Friday, 19th September	135,800	847,500	—	—	—	—	—	—	—	—	—
Saturday, 20th September	125,300	782,000	—	—	—	—	—	—	—	—	—
Sunday, 21st September	103,950	648,770	—	—	—	—	—	—	—	—	—
Monday, 22nd September	154,350	963,350	0·08	—	—	—	—	—	—	—	—
Tuesday, 23rd September	141,750	884,680	0·04	—	½	—	—	—	—	—	—
Wednesday, 24th September	110,600	690,300	—	—	—	—	—	—	—	—	—
Thursday, 25th September	101,850	635,620		—	—	—	—	—	—	—	—
Friday, 26th September	80,840	504,500	—	—	—	—	—	—	—	—	—
Saturday, 27th September	106,050	661,900	0·02	—	—	—	—	—	—	—	—
Sunday, 28th September	81,540	508,830	—	—	—	—	—	—	—	—	—
Monday, 29th September	105,000	655,300	—	—	—	—	—	—	—	—	—
Tuesday, 30th September	103,600	646,630	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Wednesday, 1st October	132,300	825,700	0·03	—	—	—	—	—	—	—	—
Thursday, 2nd October	106,050	661,900	0·03	—	—	—	—	—	—	—	—
Friday, 3rd October	164,500	1,026,400	0·16	—	—	—	—	—	—	—	—
Saturday, 4th October	130,900	816,950	—	—	—	—	—	—	—	—	—
Sunday, 5th October	100,100	624,720	—	—	—	—	—	—	—	—	—
Monday, 6th October	108,150	674,930	0·02	—	—	—	—	—	—	—	—
Tuesday, 7th October	118,650	740,530	—	—	—	—	—	—	—	—	—
Wednesday, 8th October	105,000	655,300	—	—	—	—	—	—	—	—	—
Thursday, 9th October	182,000	1,135,700	—	Clock stopped. Total for week, 1·38 ins.	3	2	¾	½	—	—	—
Friday, 10th October	162,750	1,015,600	—		—	—	—	—	—	—	—
Saturday, 11th October	113,050	705,520	—		—	—	—	—	—	—	—
Sunday, 12th October	114,800	716,450	—		1	—	—	—	—	—	—
Monday, 13th October	287,000	1,791,000	—		7½	2½	1	½	—		—
Tuesday, 14th October	313,250	1,954,680	—		5	4¼	2	2	¼	—	—

Wednesday, 15th October	150,500	939,200	—		½	—	—	—	—	—	—
Thursday, 16th October	255,800	1,596,300	—		2½	1¼	—	—	—	—	—
Friday, 17th October	243,700	1,520,850	0·34	—	1½	1	—	—	—	—	—
Saturday, 18th October	192,800	1,203,200	0·11	—	½	—		—	—	—	—
Sunday, 19th October	89,600	559,130	—	—	—	—	—	—	—	—	—
Monday, 20th October	208,950	1,303,900	0·30	—	2¾	2	½	—	—	—	—
Tuesday, 21st October	183,050	1,142,280	0·01	—	½	—	—	—	—	—	—
Wednesday, 22nd October	236,950	1,478,500	0·28	—	3	1½	¾	½	—	—	
Thursday, 23rd October	173,250	1,081,100	0·02	—	—	—	—	—	—	—	—
Friday, 24th October	150,150	937,000	0·20	—	—	—	—	—	—	—	—
Saturday, 25th October	132,300	825,700	0·05	—	—	—	—	—	—	—	—
Sunday, 26th October	186,550	1,164,200	0·23	—	2¾	1¼	1	½	—	—	—
Monday, 27th October	146,300	913,100	0·02	—	—	—	—	—	—	—	—
Tuesday, 28th October	132,300	825,680	0·04	—	—	—	—	—	—	—	—
Wednesday, 29th October	122,500	764,530	0·05	—	—	—	—		—	—	—
Thursday, 30th October	114,800	716,400	0·05	—	—	—	—	—	—	—	—
Friday, 31st October	136,500	852,000	0·02	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Saturday, 1st November	89,600	559,100	—	—	—	—	—	—	—	—	—
Sunday, 2nd November	77,000	480,500	—	—	—	—	—	—	—	—	—
Monday, 3rd November	123,200	768,900	—	—	—	—	—	—	—	—	—
Tuesday, 4th November	124,600	777,580	—	—	—	—	—	—	—	—	—
Wednesday, 5th November	118,300	738,350	0·01	—	—	—	—	—	—	—	—
Thursday, 6th November	140,000	873,800	0·08	—	—	—	—	—	—	—	—
Friday, 7th November	131,250	819,000	0·01	—	—	—	—	—	—	—	—
Saturday, 8th November	205,100	1,279,800	—	Clock stopped. Total for week 0·26 inches.	4	2¾	2¼	1½	½	—	—
Sunday, 9th November	136,850	854,100	—		—	—	—	—	—	—	—
Monday, 10th November	140,000	873,800	—		—	—	—	—	—	—	—
Tuesday, 11th November	138,950	867,180	—		—	—	—	—	—	—	—
Wednesday, 12th November	93,450	583,200	—		—	—	—	—	—	—	—
Thursday, 13th November	89,940	561,250	—		—	—	—	—	—	—	—
Friday, 14th November	94,150	587,500	—	—	—	—	—	—	—	—	—

Saturday, 15th November	78,750	491,400	—	—	—	—	—	—	—		—
Sunday, 16th November	62 300	388,800	—	—	—	—	—	—	—		—
Monday, 17th November	84,000	524,200	—	—	—	—	—	—	—	—	—
Tuesday, 18th November	98,000	611,550	—	—	—	—	—	—	—	—	—
Wednesday, 19th November	112,340	701,150	—	—	—	—	—	—	—	—	—
Thursday, 20th November	114,450	714,270	—	—	—	—		—	—	—	—
Friday, 21st November	145,950	910,950	—	—	—	—	—	—	—	—	—
Saturday, 22nd November	100,800	629,150	—	—	—	—	—	—	—	—	—
Sunday, 23rd November	91,350	570,050	—	—	—	—		—	—	—	—
Monday, 24th November	141,750	884,800	—	—	—	—	—	—	—	—	—
Tuesday, 25th November	119,350	744,880	0·01	—	—	—	—	—	—	—	—
Wednesday, 26th November	95,900	598,400	—	—	—	—	—	—	—	—	—
Thursday, 27th November	86,800	541,630	—	—	—	—	—	—	—	—	—
Friday, 28th November	201,600	1,258,200	0·62	—	2½	2½	1½	1½	—	—	—
Saturday, 29th November	120,750	753,570	0·04	—	½	—	—	—	—	—	—
Sunday, 30th November	99,050	618,100	0·09	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1902—*continued.*											
Monday, 1st December -	186,200	1,162,000	—	—	3½	2½	2	1½	—	—	—
Tuesday, 2nd December -	204,350	1,275,280	—	—	1¾	1	¼	—	—	—	—
Wednesday, 3rd December -	176,050	1,098,600	—	—	½	—	¼	—	—	—	—
Thursday, 4th December -	140,350	876,000	—	—	—	—	—	—	—	—	—
Friday, 5th December - -	127,400	795,150	—	—	—	—	—	—	—	—	—
Saturday, 6th December -	119,350	744,890	—	—	—	—	—	—	—	—	—
Sunday, 7th December - -	111,300	694,690	—	—	—	—	—	—	—	—	—
Monday, 8th December -	133,330	832,200	—	—	—	—	—	—	—	—	—
Tuesday, 9th December -	130,900	816,900	—	—	—	—	—	—	—	—	—
Wednesday, 10th December -	93,800	585,320	—	—	—	—	—	—	—	—	—
Thursday, 11th December -	88,200	550,450	—	—	—	—	—	—	—	—	—
Friday, 12th December -	87,840	548,150	—	—	—	—	—	—	—	—	—
Saturday, 13th December -	109,200	681,500	—	—	—	—	—	—	—	—	—
Sunday, 14th December -	75,950	473,950	—	—	—	—	—	—	—	—	—

Monday, 15th December	176,740	1,102,900	0·26	—	1¾	1¼	1	1	¼	—	—
Tuesday, 16th December	232,400	1,450,280	0·27	—	2	1	½	—	—	—	—
Wednesday, 17th December	210,700	1,314,800	0·17	—	3½	2¾	¾	½	—	—	—
Thursday, 18th December	200,900	1,253,600	0·18	—	½	—	—	—	—	—	—
Friday, 19th December	173,250	1,081,000	0·07	—	½	—	—	—	—	—	—
Saturday, 20th December	140,000	873,800	—	—	—	—	—	—	—	—	—
Sunday, 21st December	150,150	937,000	0·10	—	—	—	—	—	—	—	—
Monday, 22nd December	163,100	1,017,750	0·04	—	—	—	—	—	—	—	—
Tuesday, 23rd December	129,950	811,080	—	—	—	—	—	—	—	—	—
Wednesday, 24th December	105,000	655,300	—	—	—	—	—	—	—	—	—
Thursday, 25th December	87,500	546,000	0·10	—	½	—	—	—	—	—	—
Friday, 26th December	88,190	550,300	—	—	—	—	—	—	—	—	—
Saturday, 27th December	82,250	513,220	—	—	—	—	—	—	—	—	—
Sunday, 28th December	119,000	742,670	0·20	—	½	—	—	—	—	—	—
Monday, 29th December	114,100	712,080	—	—	—	—	—	—	—	—	—
Tuesday, 30th December	277,550	1,731,880	0·45	—	1½	1½	¼	—	—	—	—
Wednesday, 31st December	168,000	1,048,300	—	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1903.											
Thursday, 1st January	142,450	889,000	·02	—	—	—	—	—	—	—	—
Friday, 2nd January	196,700	1,227,300	·19	—	1½	—	½	—	—	—	—
Saturday, 3rd January	212,800	1,328,000	·24	—	1½	1½	1	1	¼	—	—
Sunday, 4th January	—	—	—	—	—	—	—	—	—	—	—
Monday, 5th January	280,000	1,747,200	·46	—	7½	7½	3	3	—	—	—
Tuesday, 6th January	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 7th January	291,500	1,819,000	·69	—	5½	2¾	1¾	¾	—	—	—
Thursday, 8th January	228,200	1,424,000	·07	—	½	—	—	—	—	—	—
Friday, 9th January	190,400	1,188,000	·08	—	½	—	—	—	—	—	—
Saturday, 10th January	222,600	1,389,000	·21	—	2½	1½	½	—	—	—	—
Sunday, 11th January	—	—	—	—	—	—	—	—	—	—	—
Monday, 12th January	—	—	—	—	—	—	—	—	—	—	—
Tuesday, 13th January	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 14th January	—	—	—	—	—	—	—	—	—	—	—

Thursday, 15th January	—			—	—		—	—	—		—
Friday, 16th January	—	—		—	—	—	—	—		—	—
Saturday, 17th January	—		—	—	—	—	—	—	—	—	—
Sunday, 18th January	—	—	—	—	—	—	—	—		—	—
Monday, 19th January		—	—	—	—		—	—	—	—	—
Tuesday, 20th January	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 21st January	—	—	—	—	—	—	—	—	—	—	—
Thursday, 22nd January	150,850	941,400	·20	—	1¼	1¼	¼	—	—	—	—
Friday 23rd January	—	—	—	—	—	—	—	—	—	—	—
Saturday, 24th January	175,700	1,096,500	·21	—	1	1	—	—	—	—	—
Sunday, 25th January	—	—	—	—	—	—	—	—	—	—	—
Monday, 26th January	—	—	—	—	—	—	—	—	—		—
Tuesday, 27th January	—	—	—	—	—	—	¼	—	—	—	—
Wednesday, 28th January	—	—	—	—	—	—	—	—	—	—	—
Thursday, 29th January	—	—	—	—	—	—	—	—	—	—	—
Friday, 30th January	—	—	—	—	—	—	—	—	—	—	—
Saturday, 31st January		—	—	—	—	—	—	—		—	—

MACCLESFIELD SEWAGE—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1903—*continued.*											
Sunday, 1st February	158,550	989,500	·10	—	½	—	—	—	—	—	—
Monday, 2nd February	161,350	1,007,000	·20	—	—	—	—	—	—	—	—
Tuesday, 3rd February	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 4th February	—	—	—	—	—	—	—	—	—	—	—
Thursday, 5th February	—	—	—	—	—	—	—	—	—	—	—
Friday, 6th February	118,300	738,400	·05	—	—	—	—	—	—	—	—
Saturday, 7th February	—	—	—	—	—	—	—	—	—	—	—
Sunday, 8th February	—	—	—	—	—	—	—	—	—	—	—
Monday, 9th February	144,550	902,100	·14	—	—	—	—	—	—	—	—
Tuesday, 10th February	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 11th February	—	—	—	—	—	—	—	—	—	—	—
Thursday, 12th February	—	—	—	—	—	—	—	—	—	—	—
Friday, 13th February	—	—	—	—	—	—	—	—	—	—	—
Saturday, 14th February	141,750	884,700	·07	—	—	—	—	—	—	—	—

Sunday, 15th February -	182,350	1,138,000	·24	—	1½	1		—	—	—	—
Monday, 16th February -	—	—	—	—	—	—	—	—	—	—	—
Tuesday, 17th February -	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 18th February -	—	—	—	—	—		—	—	—	—	—
Thursday, 19th February -	—	—	—	—	—	—	—	—	—	—	—
Friday, 20th February - -	99,040	618,000	·02	—	—	—	—	—	—	—	—
Saturday, 21st February -	144,900	904,400	·33	—	1	—	—	—	—	—	—
Sunday, 22nd February -	163,450	1,020,000	·23	—	1¼	—	—	—	—	—	—
Monday, 23rd February -	—	—	—	—	—	—	—	—	—	—	—
Tuesday, 24th February -	—	—	—	—	—	—	1½	1½	—	—	—
Wednesday, 25th February -	281,740	1,758,000	·31	—	4	1½	1½	1	—	—	—
Thursday, 26th February -	239,050	1,491,800	·12	—	1½	1	1	¾	—	—	—
Friday, 27th February - -	194,240	1,212,200	·06	—	—	—	—	—	—	—	—
Saturday, 28th February -	152,600	952,400	·04	—	—	—	—	—	—	—	—

MACCLESFIELD SEWAGE– *continued.*

DATE.	Total Discharge per 24 hours		Rainfall.	REMARKS.	Total hours overflow working.	Greatest number of hours the overflow was working consecutively.	Number of hours the storm-flow rate exceeded three times the maximum D. W. rate.	Consecutive hours.	Number of hours flow exceeded 3½ times maximum D. W. rate.	Consecutive hours.	REMARKS.
	Cubic feet.	Gallons.	Inches.								
1903.											
Sunday, 1st March - -	156,100	974,200	·20	—	1½	1½	1	1	—	—	—
Monday, 2nd March - -	256,900	1,603,000	·28	—	6½	3	½	—	—	—	—
Tuesday, 3rd March - -	258,000	—	·16	—	2½	1½	¼	—	—	—	—
Wednesday, 4th March -	157,090	1,085,500	·14	—	¾	—	—	—	—	—	—
Thursday, 5th March - -	223,300	1,393,500	·08	—	—	—	—	—	—	—	—
Friday, 6th March - -	—	—	—	—	—	—	—	—	—	—	—
Saturday, 7th March - -	156,800	978,500	·08	—	½	—	—	—	—	—	—
Sunday, 8th March - -	—	—	—	—	—	—	—	—	—	—	—
Monday, 9th March - -	129,500	808,200	·05	—	—	—	—	—	—	—	—
Tuesday, 10th March - -	242,550	—	·20	—	2¾	1½	—	—	—	—	—
Wednesday, 11th March -	168,700	1,052,800	·02	—	—	—	—	—	—	—	—
Thursday, 12th March - -	—	—	—	—	—	—	—	—	—	—	—
Friday, 13th March - -	210,350	1,312,500	·30	—	4¼	3¼	1	½	—	—	—
Saturday, 14th March - -	272,300	1,699,300	·30	—	4	2½	2	1¼	—	—	—

Sunday, 15th March	150,885	1,041,800	·01	—	—	—	—	—	—	—	—
Monday, 16th March	—	—	—	—	—	—	—	—	—	—	—
Tuesday, 17th March	195,300	—	·16	—	2	2	—	—	—	—	—
Wednesday, 18th March	332,900	1,952,500	·15	—	5¼	3¾	½	—	—	—	—
Thursday, 19th March	180,250	1,125,000	—	—	½	—	—	—	—	—	—
Friday, 20th March	—	—	—	—	—	—	—	—	—	—	—
Saturday, 21st March	—	—	—	—	—	—	—	—	—	—	—
Sunday, 22nd March	—	—	—	—	—	—	—	—	—	—	—
Monday, 23rd March	—	—	—	—	—	—	—	—	—	—	—
Tuesday, 24th March	—	—	—	—	—	—	—	—	—	—	—
Wednesday, 25th March	—	—	—	—	—	—	—	—	—	—	—
Thursday, 26th March	—	—	—	—	—	—	—	—	—	—	—
Friday, 27th March	—	—	—	—	—	—	—	—	—	—	—
Saturday, 28th March	—	—	—	—	—	—	—	—	—	—	—
Sunday, 29th March	—	—		—	—	—	—	—	—	—	—
Monday, 30th March	—	—	—	—	—	—	—	—	—	—	—
Tuesday, 31st March		—	—	—	—	—	—	—	—	—	—

ROCHDALE STORM WATER RECORD.

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall : Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
July 9th, Wednesday - -	2.20 a.m.–3.30 a.m.; 7.0 p.m.–7.45 p.m.	1	55	—	—	—	0·22—0·12 0·08	1.30 a.m.–4.0 a.m. ; 6.30 p.m.–7.0 p.m.	4,717,500	
July 10th, Thursday - -	5.30 a.m.–7.30 a.m.	2	—	—	—	—	0·23—0·21	5.0 a.m.–7.0 a.m.	5,163,000	
July 21st, Monday - - -	2.30 a.m.–3.0 a.m.	—	30	—	—	—	0·08	2.0 a.m.–4.0 am.	3,460,000	
July 26th, Saturday - -	2.35 a.m.–6.35 a.m.; 6.0 p.m.–6.30 p.m.; 10.20 p.m.–11.15 p.m.	5	25	4	2	30	0·59—0·41 0·08	2.0 a.m.–6.0 a.m. ; 10.0 p.m.–11.0 p.m.	5,398,000	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mns.		Hrs.	Mins.			Gallons.	
August 3rd, Sunday - -	3.30 a.m.–4.15 a.m.; 8.5 p.m.–8.55 p.m.	1	35	—	—	—	0·25—0·19 0·06	1.0 a.m.–7.0 a.m.; 7.0 p.m.–8.0 p.m.	3,931,000	
August 6th, Wednesday -	9.40 p.m.–11.20 p.m.	1	40	—	—	—	0·50—0·20 0·30	8.0 a.m.–noon; 10.0 p.m.–midnight.	4,481,500	
August 8th, Friday - -	5.0 a.m.–5.45 a.m.	—	45	—	—	—	0·08	—	3,538,000	
August 10th, Sunday - -	2.25 a.m.–2.50 a.m.; 5.0 a.m.–5.50 a.m.; 6.10 a.m.–6.50 a.m.; 7.20 a.m.–7.40 a.m.	2	15	—	—	—	0·32—0·19	2.0 a.m.–6.0 a.m.	3,984,000	
August 17th, Sunday - -	9.0 a.m.–10.20 a.m.; 1.30 p.m.–5.0 p.m.; 5.30 p.m.–6.30 p.m.; 7.20 p.m.–7.40 p.m.; 8.5 p.m.–10.25 p.m.	8	30	4	—	45	0·72—0·14 0·25 0·14	8.0 a.m.–10.0 a.m.; 2.0 p.m.–4.0 p.m.; 8.0 p.m.–10.0 p.m.; remainder distributed.	6,500,000	
August 18th, Monday - -	3.20 a.m.–3.40 a.m.; 6.30 a.m.–7.15 a.m.	1	5	—	—	—	0·03	3.0 a.m.–5.0 a.m.	3,564,000	
August 19th, Tuesday - -	4.20 a.m.–5.10 a.m.	—	50	—	-	—	No rainfall recorded by gauge.	—	3,303,500	
August 22nd, Friday - -	10.30 p.m.–11.30 p.m.	1	—	—	—	—	0·13	8.0 p.m.–midnight.	3,271,000	
August 23rd, Saturday - -	12.40 a.m.–1.0 a.m.; 4.20 a.m.–6.30 a.m.; 6.45 a.m.–7.40 a.m.	3	25	—	—	—	0·22	4.0 a.m.–7.0 a.m.	4,560,000	
August 24th, Sunday - -	5.30 a.m.–5.55 a.m.	—	25	—	—	—	0·04	5.0 a.m.–5.30 a.m.	3 066,200	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
September 2nd, Tuesday -	8.20 p.m.–8.50 p.m.; 9.20 p.m.–9.35 p.m.; 10.30 p.m.–10.40 p.m.	—	55	—	—	—	0·19	7.0 p.m.–11.0 p.m.	3,800,000	
September 15th, Monday -	10.30 p.m.–midnight.	1	30	—	—	—	0·25	10.30 p.m.–midnight.	3,984,000	
September 16th, Tuesday -	Midnight–12.40 a.m., 1.20 a.m.–3.0 a.m.; 4.20 a.m. –5.25 a.m.	3	25	—	—	—	0·24	Midnight–5.0 a.m.	5,687,000	
September 17th, Wednesday -	4.20 a.m.–5.40 a.m.	1	20	—	—	—	0·02	At 4.0 a.m.	4,403,000	
September 23rd, Tuesday -	3.0 a.m.–3.40 a.m.; 4.50 am.–5.40 a.m.	1	30	—	—	—	0·02	At 4.30 a.m.	4,848,500	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
October 9th, Thursday -	8.30 p.m.–9.20 p.m.	—	50	—	—	—	0·37—0·18	7.0 p.m.–10.0 p.m.; remainder fell between 2.0 p.m. and 11.0 p.m. (distributed)	5,242,000	
October 10th Friday - -	4.0 a.m.–4.50 a.m.	—	50	—	—	—	0·17	3.0 a.m.–4.0 a.m.	4,665,000	Storm water sample, 1 p.m.
October 12th, Sunday - -	10.0 p.m.–midnight	2	—	—	—	—	0·15	7.30 p.m.–midnight	3,879,000	
October 13th, Monday - -	1.0 a.m.–6.30 a.m.; 9.15 p.m.–10.15 p.m.	7	30	—	—	—	0·22	12.30 a.m.–10.30 a.m.	8,440,000	Total volume delivered at outlet = 2¼ times the average dry weather discharge.
October 14th, Tuesday - -	Midnight–5.40 a.m.	5	40	—	—	—	No rainfall recorded on gauge	—	7,052,000	
October 15th, Wednesday -	11.40 p.m.–midnight	—	20	—	—	—	,, ,,	—	4,507,500	
October 16th, Thursday- -	Midnight–3.0 a.m.; 8.40 p.m.–11.10 p.m.	5	30	—	—	—	,, ,,	—	7,052,000	
October 17th, Friday - -	Midnight–1.30 a.m.; 2.0 a.m.–4.10 a.m.	3	40	—	—	—	,, ,,	—	6,526,000	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.	Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.	Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
October 18th, Saturday - -	1.30 a.m.–2.30 a.m.	1 —	—	— —	0·12	Midnight and 3.0 a.m.	4,351,000	
October 20th, Monday - -	4.50 a.m.–5.20 a.m.; 5.50 a.m.–8.45 a.m.	3 25	—	— —	0·21	6.0 a.m.–11.30 a.m.	5,268,000	
October 22nd, Wednesday -	3.10 a.m.–7.40 a.m.	4 30	—	— —	No rainfall recorded by gauge	—	5,530,000	
October 25th, Saturday - -	3.20 a.m.–3.40 a.m.	— 20	—	— —	0·07	3.0 a.m.–7.0 a.m.	2,989,500	
October 26th, Sunday - -	3.50 a.m.–7.0 a.m.	3 10	—	— —	0·06	11.0 a.m.–5.0 p.m.	3,931,000	
October 30th, Thursday- -	2.20 a.m.–3.15 a.m.	— 55	—	— —	0.06	2.0 a.m.–3.30 a.m.	4,455,000	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
November 8th, Saturday -	12.30 p.m.–2.15 p.m.; 11.0 p.m.–midnight	2	45	4	—	45	0·46—0·31 0·07	Noon–1.30 p.m. 11.0 p.m.–11.30 p.m.	5,242,000	
November 9th, Sunday - -	1.0 p.m.–3.0 p.m.; 9.50 p.m.–10.10 p.m.	2	20	—	—	—	0·24—0·14	1.0 p.m.—2.0 p.m.	4,770,000	
November 10th, Monday -	12.50 a.m.–1.0 a.m.; 2.10 a.m.–3.10 a.m.; 5.0 a.m.–5.40 a.m.	1	50	4	—	20	0·09	1.0 a.m.–6 a.m.	3,696,500	
November 24th, Monday -	5 p.m.–6 p.m.; 7.10 p.m. –7.30 p.m.; 7.50 p.m.–8.20 p.m.	1	50	—	—	—	0·30 0·20	All fell between 3.0 p.m. and 8.30 p.m. 3.30 p.m.–6.0 p.m.	5,242,000	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1902.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
December 1st, Monday - -	10.45 p.m.–midnight	1	15	—	—	—	No rainfall recorded by gauge	—	4,665,000	
December 3rd, Wednesday -	4.20 a.m.–6.0 a.m.	1	40	—	—	—	,, ,,	—	3,538,000	
December 15th, Monday -	12.30 a.m.–2.15 a.m.; 3.0 a.m.–3.20 a.m.; 2.20 p.m.–3.20 p.m.	3	10	4	1	30	0·28—0·23	1.0 a.m.–2.0 a.m.	4,953,000	
December 16th, Tuesday -	2.30 a.m.–6.30 a.m.; 7.0 a.m.–11.20 a.m.; 1.15 p.m.–2.15 p.m.	9	20	4	2	15	0·82—0·69	2.0 a.m.–10.0 a.m.	9,018,000	Total volume delivered at outfall=2¾ times the average dry weather discharge.
December 17th, Wednesday -	5.50 a.m.–6.10 a.m.; 10.30 p.m.–11.40 p.m.		30	—	—	—	No rainfall recorded by gauge.	—	3,616,500	
December 18th, Thursday -	6.0 a.m.–6.40 a.m.; 8.40 a.m.–9.10 a.m.	1	10	—	—	—	,, ,,	—	5,110,000	
December 19th, Friday - -	2.50 a.m.–3.40 a.m.	—	50	4	—	25	,, ,,	—	3,273,500	
December 25th, Thursday -	9.0 p.m.–9.40 p.m.	—	40	—	—	—	0·07	6.0 p.m.–9.0 p.m.	3,643,000	
December 27th, Saturday -	11.15 p.m.–midnight.	—	—	—	—	—	0·08	10.30 p.m.–midnight.	3,958,500	
December 28th, Sunday - -	Midnight–2.30 a.m.; 5.30 a.m.–6.45 a.m.	3	45	4	2	30	0·13—0·09 0·04	Midnight–1.30 a.m.; 2.0 a.m.–5.0 a.m.	4,901,000	
December 29th, Monday -	7.0 p.m.–8.0 p.m.	1	—	—	—	—	0·21	Distributed from 6 a.m.–6 p.m.	3,491,000	
December 30th, Tuesday -	Midnight–1 a.m.; 6.30 a.m.–7.0 a.m.	1	30	—	—	—	No rainfall recorded by gauge.	—	3,800,000	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1903.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
January 1st, Thursday - -	10.30 p.m.–11.20 p.m.	—	50	—	—	—	0·07	9.30 p.m.–11.30 p.m.	3,296,000	
January 2nd, Friday - -	12.20 a.m.–12.40 a.m.; 6.30 a.m.–7.30 a.m.	1	20	—	—	—	0·21—0·16	7.0 a.m.–9.0 a.m.	4,298,000	
January 3rd, Saturday - -	5.10 a.m.–7.20 a.m.	2	10	4	1	—	0·12	5.0 a.m.–7.0 a.m.	3,512,000	
January 4th, Sunday - -	8.30 a.m.–9.30 a.m.	1	—	—	—	—	0·04	8.0 a.m.–9.30 a.m.	3,433,000	
January 5th, Monday - -	Noon–5.10 p.m.; 8.20 p.m.–8.40 p.m.; 9.0 p.m.–11.15 p.m.	7	45	6 5 4	1 2 2	5 10 30	0·67—0·50 0·15	9.0 a.m.–4.0 p.m.; 8.30 p.m.–11.0 p.m.	8,650,000	Total volume delivered at outfall=2½ times average D.W. discharge. Storm water samples taken 12 noon, 2 p.m., 3.10 p.m.
January 6th, Tuesday - -	Midnight–1.0 a.m.; 10.15 p.m.–11.0 p.m.	1	45	—	—	—	0·08—0·06	9.30 p.m.–10.0 p.m.	3,669,000	
January 7th, Wednesday -	6.30 a.m.–7.40 a.m.; 4.20 p.m.–5.40 p.m.	2	30	—	—	—	0·26—0·13 0·13	6.0 a.m.–7.0 a.m.; 4.0 p.m.–6.0 p.m.	4,455,000	
January 8th, Thursday - -	10.10 p.m.–11.40 p.m.	1	30	—	—	—	0·10	7.0 p.m.–10.30 p.m.	4,507 500	
January 9th, Friday - -	12.30 p.m.–1.0 p.m.; 9.20 p.m. midnight.	3	10	4	—	20	0·19—0·09 0·10	9.30 a.m.–11 a.m.; 9.30 p.m.–10.30 p.m.	5,163,000	
January 10th, Saturday - -	Midnight–1.30 a.m.; 4.0 p.m.–5.0 p.m.	2	30	6 5 4	— — 1	20 45 10	0·12—0·07 0·05	Midnight–1.0 a.m.; 3.30 p.m.–4.30 p.m.	4,377,000	
January 22nd, Thursday -	5.0 p.m.–6.45 p.m.	1	45	—	—	—	0·19	5.0 p.m.–7.0 p.m.	4,822,500	
January 27th, Tuesday - -	Midnight–4.45 a.m.	4	45	—	-	—	0·52—0·28	Midnight–4.15 a.m.	5 032,500	Rain fell from 10 p.m. on 26th to 8 p.m. on 27th.

Rochdale Storm Water Record—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
1903.		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
February 9th, Monday	3.45 a.m.–7.0 a.m.	3	15	4	—	45	0·12	4.0 a.m.–7.0 a.m.	4,298,000	
February 20th, Friday	3.0 a.m.–3.30 a.m.	—	30	—	—	—	No rainfall recorded by gauge.	—	3,284,200	
February 22nd, Sunday	6.40 a.m.–8.30 a.m.: 7.0 p.m.–9.0 p.m.	2	50	—	—	—	0·62—0·39 0·17	6.0 a.m.–11.30 a.m.; 7.0 p.m.–8.0 p.m.	5,845,000	
February 24th, Tuesday	11.30 p.m.–midnight	—	30	—	—	—	0·41—0·20 0·15	4.0 p.m.–7.0 p.m.; 7.30 p.m.–8.0 p.m.	4,246,000	
February 25th, Wednesday	Midnight–12.30 a.m.; 2.20 a.m.–3.0 a.m.	1	10	—	—	—	0·28—0·15 0·10	Midnight–6.0 a.m.; 4.0 p.m.–4.30 p.m.	5,032,000	
February 26th, Thursday	Midnight–12.50 a.m.	—	50	—	—	—	0·05	Midnight–3.0 a.m.	3,119,000	

ROCHDALE STORM WATER RECORD—(*continued*).

Date.	Time.	Period when the rate of flow exceeded three times the dry weather rate.		Rates of flow above three times the dry weather rate in multiples of the dry weather rate.	Corresponding duration.		Rainfall: Midnight to midnight.	Hours between which rain fell.	Total volume discharged in 24 hours.	Remarks.
		Hrs.	Mins.		Hrs.	Mins.			Gallons.	
1903.										
March 14th, Saturday - -	3.40 a.m.–4.15 a.m.	—	35	—	—	—	0·23—0·15 0·13	Midnight–4.0 a.m.; 8.0 p.m.–11.0. p.m.	4,010,000	0·30 rain 6.0 p.m. to midnight on 13th.
March 18th, Wednesday -	1.30 a.m.–5.30 a.m.	4	—	—	—	—	0·35—0·25 0·10	1.0 a.m.–5.0 a.m.; 5.0 a.m.–10.0 a.m.	5,241 600	

TABLE B (1).

STOCKPORT STORM WATER RECORD.

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1901.					
July 21st, Sunday - - -	6.0 p.m.–9.0 p.m.	5½	1·05	3,425,000	
July 25th, Thursday - -	3.0 a.m.–6.0 a.m.	4	2·43	6,738,000	Total volume delivered at outfall = 2½ times average dry weather discharge.
	6.0 p.m.–9.0. p.m.	3			
	9.0 p.m.–midnight.	5½			
July 26th, Friday . - -	Midnight–3.0 a.m.	3½	0·16	5,865,000	
	3.0 a.m.–6 a.m.	4½			
July 28th, Sunday - - -	Midnight–3.0 a.m.	4½	0·22	4,225,000	
	3.0 a.m.–6.0 a.m.	3			
	6.0 a.m.–9.0 a.m.	3			

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1901.					
August 26th, Monday - -	Midnight-3.0 a.m. 5.0 p.m.-9.0 p.m.	4 4½	0·50	3,662,500	Storm water samples taken at 5 p.m., 6 p.m. and 7 p.m
August 31st, Saturday - -	Midnight-3.0 a m.	3	0·09	3,093,900	

Stockport Storm Water Record—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1901.					
September 8th, Sunday - -	6.0 a.m.–9.0 a.m.	6	0·09	2,943,700	
September 17th, Tuesday -	9.0 p.m.–midnight.	4	0·12	4,125 000	
September 20th, Friday - -	9.0 p.m.–midnight.	5	0·24	3,350,000	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1901.					
October 1st, Tuesday - -	9.0 a.m.–noon.	3	0·04	2,631,300	
October 2nd, Wednesday -	Midnight–3.0 a.m.	4	0·11	2,450,000	
October 3rd, Thursday - -	9.0 p.m.–midnight.	3	0·04	2,994,000	
October 4th, Friday - -	Midnight–3.0 a.m. 3.0 a.m.–to 6.0 a.m.	4 3	0·33	4,200,500	
October 6th, Sunday - -	6.0 a.m.–9.0 a.m. 6.0 a.m.–noon.	10 3½	0·55	3,912,800	
October 8th, Tuesday - -	6.0 p.m.–9.0 p.m. 9.0 p.m.–midnight. 6.0 p.m.–midnight.	3½ 4½ 4	0·49	4,731,400	
October 9th, Wednesday -	3.0 a.m.–6.0 a.m. 6.0 a.m.–9.0 a.m. 9.0 a.m–noon.	3 3 3	0·15	5,007,000	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1901.					
November 10th, Sunday -	9.0 p.m.-midnight.	3½	0·01	2,431,300	
November 11th Monday -	Midnight-3.0 a.m.	5	0·25	5,700,000	
	6.0 p.m.-9.0 p.m.	4			
	9.0 p.m.-midnight.	6			
	6.0 p.m.-midnight.	4½			
November 12th, Tuesday -	—	--	1·67	6,013,000	Beyond this river filled sewer, unable to pump for 8 hours.
November 18th, Monday -	6.0 p.m.-9.0 p.m.	3	0·16	4,150,000	
	9.0 p.m.-midnight.	6			
November 19th, Tuesday -	Midnight-3.0 a.m.	5	0·31	5,900,000	
November 20th, Wednesday -	9.0 a.m.-noon.	3	0·47	5,912,500	
	9.0 p.m.-midnight.	4			
November 21st, Thursday -	Midnight-3.0 a.m.	4	0·29	6,457,000	Total volume of sewage and storm water delivered at outfall=2½ times average dry weather discharge.
	6.0 a.m.-9.0 a.m.	3			
	6.0 p.m.-9.0 p.m.	3½			
	9.0 p.m.-midnight.	3½			
November 22nd, Friday -	Midnight-3.0 a.m.	4	0·03	6,407,000	Total volume delivered at outfall=2½ times average dry weather discharge.
	3.0 a.m.-6.0 a.m.	3			
	6.0 a.m.-9.0 a.m.	3			
	6.0 a.m.-noon.	3			

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1901.					
December 7th, Saturday -	6.0 a.m.–9.0 a.m. 9.0 p.m–midnight.	3 4	·22	3,768,700	
December 8th, Sunday - -	Midnight–3.0 a.m. 3.0 a.m.–6.0 a.m. 6.0 a.m.–9.0 a.m. Midnight–noon.	4½ 5 4	0·77	4,225,000	River backed up into sewer and stopped pumping.
December 9th Monday - -	6.0 a.m.–9.0 a.m. Noon–3.0 p.m. 6.0 a.m.–3.0 p.m. 6.0 a.m.–midnight, 9.0 p.m.–midnight.	4½ 3 3 3 4	0·23	5,581,500	
December 10th, Tuesday -	Midnight–3.0 a.m. 3.0 a.m.–6.0 a.m. 6 p.m.–9 p.m. 9 p.m.–midnight.	3 3 4 4	0·17	6,844,500	Total volume discharged at outfall = 2¾ times average dry weather discharge.
December 11th, Wednesday -	Midnight–3.0 a.m. 3.0 a.m.–6.0 a.m	4 3	0·10	5,869,000	
December 12th, Thursday -	6.0 p.m.–9.0 p.m. 9.0 p.m.–midnight. 3.0 p.m.–midnight.	4 5 3	0·34	6,256,700	
December 13th, Friday - -	Midnight–3.0 a.m. Noon–3.0 p.m. 9.0 p.m.–midnight.	3 3 3	0·06	6,830,000	Total volume discharged at outfall = 2¾ times average dry weather discharge.
December 17th, Tuesday -	9.0 p.m.–midnight.	5	0·10	4,717 800	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
January 29th, Wednesday	Midnight–3.0 a.m.	3	0·01	4,687,500	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
February 8th, Saturday -	9 p.m.–midnight.	3	0·10	3,225,000	
February 22nd, Saturday -	9 p.m.–midnight.	3	None.	3,868,700	
February 23rd, Sunday -	Midnight–3.0 a.m. 3.0 a m.–9.0 a.m.	3 3	0·07	3,749,800	
February 24th, Monday -	Noon–midnight. 6.0 p.m.–9.0 p.m.	3 4	0·27	5,312,400	
February 25th, Tuesday -	9.0 p.m.–midnight.	3	0·02	4,699,500	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
March 8th, Saturday - -	9.0 p.m.–midnight	4½	0·15	4,031,000	
March 9th, Sunday - -	9.0 p.m.–midnight.	3	0·05	3,400,000	
March 10th, Monday - -	6.0 a.m.–9.0 a.m.	4½	0·11	3,950,000	
March 14th, Friday -	9.0 p.m.–midnight.	5½	0·10	4 012,400	
March 24th, Monday - -	Midnight–3.0 a m.	3	0·12	4,625,000	
March 25th, Tuesday - -	Midnight–3.0 a.m.	4½	0·10	4,581,100	
March 26th, Wednesday -	9.0 p.m.–midnight.	4	0·14	4,556,000	
March 27th, Thursday - -	6.0 am.–9.0 a m.	3½	0·10	4,656,000	
March 31st, Monday - -	Midnight–3.0 a.m. 3.0 a.m.–6.0 a.m. 9.0 p.m.–midnight.	3 4 3	0·09	3,987,900	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
April 1st, Tuesday - -	Midnight–3.0 a.m.	3	0·10	4,250,200	
	6.0 a.m.–9.0 a.m.	3			
April 3rd, Thursday - -	6.0 p.m.–9.0 p.m.	3½	0·15	4,281,100	
April 4th, Friday - - -	3.0 a.m.–6.0 a.m.	4	0·12	5,263,000	
	6.0 a.m.–9.0 a.m.	3½			
April 5th, Saturday - -	6.0 a.m.–noon.	3½	0·38	6,068,200	Total volume delivered at outfall=2½ times average dry weather flow.
	noon–3.0 p.m.	3			
	6.0 p.m.–9.0 p.m.	3½			
	9.0 p.m.– midnight.	3			
April 6th, Sunday - -	6.0 a.m.–9.0 a.m.	3	None.	3,375,000	
	9.0 p.m.–midnight.	3			
April 7th, Monday - -	6.0 a.m.–9.0 a.m.	3	None.	3,519,000	
April 13th, Sunday - -	Midnight–3.0 a.m.	3½	0·13	3,187,800	
April 15th, Tuesday - -	6.0 p.m.–9.0 p.m.	4	0·45	5,956,000	
	9.0 p.m.–midnight.	5			
April 16th, Wednesday -	9.0 p.m.–midnight.	3	0·06	3,931,100	
April 20th, Sunday - -	6.0 p.m.–9.0 p.m.	5½	0·19	3,537,400	
April 22nd, Tuesday - -	Midnight–3.0 a.m.	3	0·08	4,156,500	
April 30th, Wednesday -	9.0 p.m.–midnight.	4	0·11	3,156,500	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
May 3rd, Saturday - -	3.0 a.m.–6.0 a.m.	3	0·36	3,575,000	
	6.0 p.m.–9.0 p.m.	4			
May 4th, Sunday - - -	3.0 a.m.–6.0 a.m.	3½	0·07	3,025,000	
May 5th, Monday -	Midnight–3.0 a.m.	3	0·10	3,256,000	
	6.0 a.m.–9.0 a.m.	3			
May 6th, Tuesday - -	6.0 p.m.–9.0 p.m.	4	0·06	3,475,000	
May 15th, Thursday - -	6.0 p.m.–9.0 p.m.	3½	0·35	4,400,000	
	9.0 p.m.–midnight.	5½			
May 16th, Friday - -	6.0 p.m.–9.0 p.m.	3½	0·20	4,812,500	
May 17th, Saturday - -	6.0 p.m.–9.0 p.m.	3	0·43	4,369,000	
	9.0 p.m.–midnight.				
May 18th, Sunday - - -	Midnight–9.0 a.m.	3½	0·12	4,681,000	
May 19th, Monday - -	9.0 p.m.–midnight.	3½	None.	3,975,000	
May 22nd, Thursday - -	6.0 p.m.–9.0 p.m.	4	None.	6,237,000	
	9.0 p.m.–midnight.	5½			
May 23rd, Friday - - -	Midnight–3.0 a.m.	3½	0·40	4,312,300	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
June 1st, Sunday - - -	3.0 a.m.–6.0 a.m.	3	0·05	2,625,000	
June 5th, Thursday - -	9.0 p.m.–midnight.	3½	0·08	3,106,100	
June 7th, Saturday - -	9.0 a.m.–noon. 6.0 p.m.–9.0 p.m.	3½ 5	0·19	4,825,000	
June 17th, Tuesday - -	3.0 a.m.–6.0 a.m.	4	0·10	3,343,800	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
July 1st, Tuesday - - -	—	—	0·11	4,287,500	Beyond this date the Reddish sewage is pumped as well as that from Stockport.
July 10th, Thursday - -	9.0 a.m.–3.0 p.m.	3	0·38	4,981,400	Storm overflows on line of sewer working freely 10 a.m.
July 26th, Saturday - -	3.0 a.m.–6.0 a.m. 6.0 a.m.–9.0 a.m.	3 3½	0·41	4,869,400	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
August 2nd, Saturday - -	9.0 p.m.–midnight.	5	0·31	4,956,300	
August 3rd, Sunday - -	Midnight–3.0 a.m. 9.0 p.m.–midnight.	3 3½	0·17	4,056,400	
August 6th, Wednesday -	9.0 a.m.–noon. 9.0 p.m.–midnight.	3 3½	0·23	4,982,400	
August 10th, Sunday - -	6.0 a.m.–9.0 a.m.	5	0·13	3,062,600	
August 17th, Sunday -	3.0 p.m.–6.0 p.m. 6.0 p.m.–9.0 p.m.	3 3½	0·41	4,563,000	
August 22nd, Friday - -	9.0 p.m.–midnight.	3½	0·10	3,437,600	
August 23rd, Saturday - -	6.0 a.m.–9.0 a.m.	3½	0·28	4,431,600	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
September 2nd, Tuesday -	9.0 p.m.–midnight.	3	None.	3,744,000	
September 3rd, Wednesday -	6.0 p.m.–9 p.m.	3	0·06	3,881,500	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
October 9th, Thursday - -	6.0 p.m.–9.0 p.m.	3	0·50	5,257,000	
	9.0 p.m.–midnight.	4			
October 10th, Friday - -	Midnight–3.0 a.m.	3½	0·18	5,606,700	
October 13th, Monday - -	Noon–midnight.	3	0·42	6,782,000	
	9.0 p.m.–midnight.	4			
October 14th, Tuesday - -	Midnight–midnight.	3	0·63	8,408,000	Total volume delivered at outfall=2¾ times average dry weather discharge.
	Midnight–3.0 a.m.	3½			
	9.0 p.m.–midnight.	4			
October 15th, Wednesday -	Noon–3.0 p.m.	3	0·24	6,732,000	
October 16th, Thursday -	3 0 a.m.–6.0 a.m.	3½	0·26	8,438,000	Total volume delivered at outfall=3 times the average dry weather flow.
	6.0 a.m.–9.0 a.m.	4			
	Noon–6.0 p.m.	3			
	9.0 p.m.–midnight.	4			
October 17th, Friday - -	3.0 a.m.–6.0 a.m.	3½	0·18	8,302,000	Total volume delivered at outfall=2¾ times average dry weather discharge.
	6.0 a.m.–9.0 a.m.	4			
	9.0 a.m.–midnight.	3			
October 18th, Saturday -	3.0 a.m.–6.0 a.m.	3½	0·14	7,113,000	Total volume delivered at outfall=2½ times average dry weather discharge.
	6.0 a.m.–noon.	3			
October 20th, Monday - -	6.0 a.m.–9.0 a.m.	3½	0·17	6,150,000	
October 22nd, Wednesday -	3.0 a.m.–3.0 p.m.	3	0·19	7,239,000	
	6.0 a.m.–9.0 a.m.	3½			
October 26th, Sunday - -	6.0 a.m.–noon	3	0·15	3,881,000	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
November 8th, Saturday -	6.0 p.m.–9.0 p.m.	3	0·33	5,068,800	
	9.0 p.m.–midnight.	3½			
November 9th, Sunday - -	9.0 p.m.–midnight.	3	0·06	4,100,000	
November 28th, Friday -	6.0 p.m.–9.0 p.m.	3	0·31	5,512,700	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution : Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1902.					
December 1st, Monday -	6.0 p.m.–9.0 p.m.	3	0·21	4,781,300	
December 2nd, Tuesday -	3.0 a.m.–6.0 a.m.	3½	0·36	8,476,000	Total volume delivered at outfall=2¾ times the average dry weather discharge.
	6.0 a.m.–noon	3			
	9.0 p.m.–midnight	3½			
December 3rd, Wednesday -	6.0 a.m.–9.0 a.m.	3½	0 07	6,075,000	
December 16th, Tuesday -	3.0 a.m.–6 a.m.	3½	0·42	8,213,500	Total volume delivered at outfall=2½ times average dry weather discharge.
	6.0 a.m.–noon	3			
	9.0 p.m.–midnight	4			
December 17th, Wednesday -	Midnight–3.0 a.m.	4	0·04	7,688,600	Total volume delivered at outfall=2½ times average dry weather discharge.
	6.0 a.m.–noon	3			
	9.0 p.m.–midnight	4			
December 18th, Thursday -	Midnight–3.0 a.m.	3½	0·19	6,870,000	Total volume delivered at outfall=2½ times average dry weather discharge.
	6.0 a.m.–noon	3			
December 28th, Sunday -	Midnight–3.0 a.m.	3½	0·18	4,613,000	
	3.0 a.m.–9.0 a.m.	3			

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1903.					
January 2nd, Friday - -	9.0 a.m.–midnight	3	0·17	5,037,700	
January 3rd, Saturday - -	6.0 a.m.–9 0 a.m. 9.0 a.m.–noon	3½ 3	0·07	5,212,000	
January 5th, Monday - -	9.0 a.m.–3.0 p.m. 6.0 p.m.–9.0 p.m. 9.0 p.m.–midnight	3 3 4	0·36	7,051,000	
January 6th, Tuesday - -	Midnight–6.0 a.m. 6.0 a.m–noon 9.0 p.m.–midnight	3½ 3 3	0·15	8,382,700	Total volume delivered at outfall=2¾ times average dry weather discharge.
January 7th, Wednesday -	6 a.m.–3.0 p.m. 6.0 p.m.–9.0 p.m. 9.0 p.m.–midnight	3 3 4	0·23	8,182,000	Total volume delivered at outfall=2¾ times average dry weather discharge.
January 8th, Thursday -	Midnight–3 a m. 6.0 a.m.–noon 9.0 p.m.–midnight	3½ 3 3	0·04	7,713,000	Total volums delivered at outfall=2¾ times average dry weather discharge.
January 9th, Friday - -	9.0 p.m.–midnight	4	0·05	6,307,500	
January 10th, Saturday -	Midnight–3.0 a.m. 3.0 a.m.–6.0 a.m. 6.0 a.m.–noon 6 p.m.–midnight	3 3½ 3 4	0·19	8,251,000	Total volume delivered at outfall=3 times average dry weather discharge.
January 11th, Sunday - -	3.0 a.m.–9.0 a.m. (due to rainfall late on day previous).	3	No rainfall.	4,400,000	
January 22nd, Thursday -	6.0 p.m.–9.0 p.m.	3	0·18	4,206,500	
January 24th, Saturday -	9.0 a.m.–noon 9.0 p.m.–midnight	3 5	0·15	6,006,500	
January 27th, Tuesday -	6.0 a.m.–noon 9.0 p.m.–midnight	3 3	0·19	6,413,200	

STOCKPORT STORM WATER RECORD—(*continued*).

Date.	Hour.	Dilution: Times the dry weather flow.	Total rainfall in 24 hours. Inches.	Total volume of sewage and storm water delivered at outfall in 24 hours.	Remarks.
1903.					
February 1st, Sunday	3.0 a.m.–6.0 a.m.	3	0·07	3,912,400	
February 9th, Monday	3.0 a.m.–6.0 a.m.	3	0·08	5,112,100	
February 21st, Saturday	3.0 p.m.–6.0 p.m.	3	0·30	6,200,000	Took storm water samples at 4.45 and 5.15 p.m.; 3 times diluted.
	6.0 p.m.–9.0 p.m.	3½			
	9.0 p.m.–midnight.	3			
February 22nd, Sunday	3.0 p.m.–6.0 p.m.	3	0·07	6,826,000	Total volume delivered at outfall=2¾ times average dry weather discharge.
	6.0 p.m.–9.0 p.m.	4			
	9.0 p.m.–midnight.	4½			
February 23rd, Monday	Midnight–3.0 a.m.	3½	0·06	5,925,000	
February 24th, Tuesday	9.0 p.m.–midnight.	4	0·07	5,931,200	
February 25th, Wednesday	Midnight–3.0 a.m.	4	0·25	9,000,000	Over 3 times diluted for whole 24 hours. Total volume delivered at outfall=3 times average dry weather discharge.
	3.0 a.m.–9.0 a.m.	3½			
	9.0 a.m.–3.0 p.m.				
	6.0 p.m.–9.0 p.m.	3			
	9.0 p.m.–midnight.	4			
February 26th, Thursday	Midnight–6.0 a.m.	3½	0·03	7,814,000	Total volume delivered at outfall=2¾ times average dry weather discharge.
	6.0 a.m.–9.0 a.m.	4			
	9.0 a.m.–noon.	3			

STOCKPORT CORPORATION.

PUMPING FIGURES.

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1901.				
Saturday, 20th July	—	2,525,000	—	—
Sunday, 21st July	—	3,425,000	—	—
Monday, 22nd July	—	2,887,500	—	—
Tuesday, 23rd July	—	2,481,300	0·04	—
Wednesday, 24th July	—	3,393,500	0·48	—
Thursday, 25th July	—	6,738,000	2·43	2½ times average D. W. volume.
Friday, 26th July	—	5,865,000	0·16	—
Saturday, 27th July	—	2,456,200	0·18	—
Sunday, 28th July	—	4,225,000	0·22	—
Monday, 29th July	—	2,287,400	—	—
Tuesday, 30th July	—	2,675,000	—	—
Wednesday, 31st July	—	2,362,300	—	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1901—*continued.*				
Thursday, 1st August	—	2,631,000	—	—
Friday, 2nd August	—	2,518,700	—	—
Saturday, 3rd August	—	2,268,800	—	—
Sunday, 4th August	—	1,862,400	—	—
Monday, 5th August	—	2,817,500	—	—
Tuesday, 6th August	—	2,206,200	·12	—
Wednesday, 7th August	—	2,606,100	·03	—
Thursday, 8th August	—	2,818,600	·07	—
Friday, 9th August	—	2,481,000	—	—
Saturday, 10th August	—	2,531,200	·06	—
Sunday, 11th August	—	1,962,400	·02	—
Monday, 12th August	—	2,962,300	·04	—
Tuesday, 13th August	—	2,262,300	—	—
Wednesday, 14th August	—	2,750,000	08	—
Thursday, 15th August	—	2,962,300	·06	—
Friday, 16th August	—	2,268,800	—	—
Saturday, 17th August	—	2,781,200	·08	—
Sunday, 18th August	—	2,125,000	—	—
Monday, 19th August	—	2,075,000	—	—
Tuesday, 20th August	—	2,087,500	—	—
Wednesday, 21st August	—	2,306,200	—	—
Thursday, 22nd August	—	2,556,100	—	—
Friday, 23rd August	—	2,175,000	—	—
Saturday, 24th August	—	1,843,700	—	—
Sunday, 25th August	—	1,743,800	—	—
Monday, 26th August	—	3,662,500	·50	Storm samples taken from 5 p.m. to 9 p.m. flow was at rate of 4½ times D. W. flow.
Tuesday, 27th August	—	2,462,500	·02	—
Wednesday, 28th August	—	2,625,000	·08	—
Thursday, 29th August	—	2,700,000	·02	—
Friday, 30th August	—	2,587,500	·04	—
Saturday, 31st August	—	3,093,000	·09	—

STOCKPORT CORPORATION—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1901—*continued.*				
Sunday, 1st September	—	1 968,700	—	—
Monday, 2nd September	—	2,600,000	—	—
Tuesday, 3rd September	—	2,600,000	—	—
Wednesday, 4th September	—	2,831,200	—	—
Thursday, 5th September	—	2,531,400	—	—
Friday, 6th September	—	2,425,000	—	—
Saturday, 7th September	—	2,228,800	—	—
Sunday, 8th September	—	2,943,700	·09	—
Monday, 9th September	—	2,556,300	—	—
Tuesday, 10th September	—	2,881,300	·04	—
Wednesday, 11th September	—	2,793,700	·03	—
Thursday, 12th September	—	2,681,200	—	—
Friday, 13th September	—	2,356,300	—	—
Saturday, 14th September	—	2,237,500	—	—
Sunday, 15th September	—	2,000,000	—	—
Monday, 16th September	—	3,106,100	·10	—
Tuesday, 17th September	—	4,125,000	·12	—
Wednesday, 18th September	—	2,531,200	—	—
Thursday, 19th September	—	2,506,200	—	—
Friday, 20th September	—	3,350,000	·24	—
Saturday, 21st September	—	2,706,000	·01	—
Sunday, 22nd September	—	1,950,000	—	—
Monday, 23rd September	—	2,131,200	—	—
Tuesday, 24th September	—	2,531,500	—	—
Wednesday, 25th September	—	2,512,500	·03	—
Thursday, 26th September	—	2,500,000	—	—
Friday, 27th September	—	2,406,300	—	—
Saturday, 28th September	—	2,262,400	—	—
Sunday, 29th September	—	1,918,900	—	—
Monday, 30th September	-	2,644,000	10	—

STOCKPORT CORPORATION—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1901—*continued.*				
Tuesday, 1st October	—	2,631,300	·04	—
Wednesday, 2nd October	—	2,450,000	·11	—
Thursday, 3rd October	—	2,994,000	·04	—
Friday 4th October	—	4,200,500	·33	—
Saturday, 5th October	—	3,369,000	·11	—
Sunday, 6th October	—	2,912,800	·55	—
Monday, 7th October	—	2,319,000	·01	—
Tuesday, 8th October	—	4,731,400	·49	—
Wednesday, 9th October	—	5,007,000	·15	—
Thursday, 10th October	—	2,856,400	·01	—
Friday, 11th October	—	2,343,900	·02	—
Saturday, 12th October	—	2,544,000	·02	—
Sunday, 13th October	—	1,962,700	—	—
Monday, 14th October	—	2,581,400	—	—
Tuesday, 15th October	—	2,600,000	—	—
Wednesday, 16th October	—	2,856,300	—	—
Thursday, 17th October	—	3,994,100	·34	—
Friday, 18th October	—	2,937,700	·05	—
Saturday, 19th October	—	2,425,300	·01	—
Sunday, 20th October	—	1,812,600	—	—
Monday, 21st October	—	2,306,500	—	—
Tuesday, 22nd October	—	2,531,500	—	—
Wednesday, 23rd October	—	2,381,300	·01	—
Thursday, 24th October	—	4,550,100	·24	—
Friday, 25th October	—	2,925,100	—	—
Saturday, 26th October	—	2,406,300	uncertain	—
Sunday, 27th October	—	1,962,700	uncertain	—
Monday, 28th October	—	2,494,000	·04	—
Tuesday, 29th October	—	2,600,000	·03	—
Wednesday, 30th October	—	2,287,700	—	—
Thursday, 31st October	—	2,418,900	—	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1901—*continued.*				
Friday, 1st November	—	2,368,800	—	—
Saturday, 2nd November	—	2,231,400	—	—
day, 3rd November	—	1,862,600	—	—
Monday, 4th November	—	2,368,000	—	—
Tuesday, 5th November	—	2,462,500	—	—
Wednesday, 6th November	—	2,593,900	·01	—
Thursday, 7th November	—	2,412,700	—	—
Friday, 8th November	—	2,400,200	—	—
Saturday, 9th November	—	2,318,900	—	—
Sunday, 10th November	—	2,431,300	·01	—
Monday, 11th November	—	5,700,000	0·25	—
Tuesday, 12th November	—	6,013,000	1·67	Ceased pumping after 5 p.m.
Wednesday, 13th November	—	3,844,000	0·04	—
Thursday, 14th November	—	3,150,000	—	—
Friday, 15th November	—	2,418,900	—	—
Saturday, 16th November	—	2,593,900	—	—
Sunday, 17th November	—	2,056,200	·02	—
Monday, 18th November	—	4,150,000	·16	—
Tuesday, 19th November	—	5,900,000	·31	—
Wednesday, 20th November	—	5,912,500	·47	—
Thursday, 21st November	—	6,457,000	·29	2½ times av. D. W. volume.
Friday, 22nd November	—	6,407,000	·03	2½ times av. D. W. volume.
Saturday, 23rd November	—	2,406,300	—	—
Sunday, 24th November	—	2,450,000	—	—
Monday, 25th November	—	2,712,500	—	—
Tuesday, 26th November	—	2,656,400	—	—
Wednesday, 27th November	—	2,762,700	·01	—
Thursday, 28th November	—	2,787,500	—	—
Friday, 29th November	—	2,556,300	—	—
Saturday, 30th November	—	2,419,400	—	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1901—*continued.*				
Sunday, 1st December	—	2,212,500	·02	—
Monday, 2nd December	—	2,887,800	—	—
Tuesday, 3rd December	—	2,981,200	—	—
Wednesday, 4th December	—	2,943,800	—	—
Thursday, 5th December	—	3,143,800	·04	—
Friday, 6th December	—	3,050,000	—	—
Saturday, 7th December	—	3,768,700	·22	—
Sunday, 8th December	—	4,225,000	·77	Ceased pumping 12.45 p.m.
Monday, 9th December	—	5,581,500	·23	—
Tuesday, 10th December	—	6,844,500	·17	2¾ times av. D. W. volume.
Wednesday, 11th December	—	5,869,000	·10	—
Thursday, 12th December	—	6,259,700	·34	—
Friday, 13th December	—	6,380,000	·06	2¾ times av. D. W. volume.
Saturday, 14th December	—	4,512,500	·03	—
Sunday, 15th December	—	3,218,900	—	—
Monday, 16th December	—	4,475,000	·05	—
Tuesday, 17th December	—	4,717,800	·10	—
Wednesday, 18th December	—	2,031,300	·03	—
Thursday, 19th December	Pumping stopped to put in screen.			
Friday, 20th December				
Saturday, 21st December				
Sunday, 22nd December				
Monday, 23rd December				
Tuesday, 24th December				
Wednesday, 25th December				
Thursday, 26th December				
Friday, 27th December				
Saturday, 28th December				
Sunday, 29th December				
Monday, 30th December				
Tuesday, 31st December				

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

Date.	Total Discharge per 24 hours.		Rainfall.	Remarks.
	Cubic feet.	Gallons.	Inches.	
1902.				
Wednesday, 1st January	Pumping stopped to put in screen.			
Thursday, 2nd January				
Friday, 3rd January				
Saturday, 4th January				
Sunday, 5th January				
Monday, 6th January				
Tuesday, 7th January				
Wednesday, 8th January				
Thursday, 9th January				
Friday, 10th January				
Saturday, 11th January				
Sunday, 12th January				
Monday, 13th January				
Tuesday, 14th January				
Wednesday, 15th January				
Thursday, 16th January				
Friday, 17th January				
Saturday, 18th January				
Sunday, 19th January				
Monday, 20th January				
Tuesday, 21st January				
Wednesday, 22nd January				
Thursday, 23rd January				
Friday, 24th January				
Saturday, 25th January				
Sunday, 26th January				
Monday, 27th January				
Tuesday, 28th January	—	4,563,000	·24	—
Wednesday, 29th January	—	4,687,500	·01	—
Thursday, 30th January	—	3,637,600	—	—
Friday, 31st January	—	3,512,300	—	—

Stockport Corporation—Pumping Figures—*continued.*

Date.	Total Discharge per 24 hours.		Rainfall.	Remarks.
	Cubic Feet.	Gallons.	Inches.	
1902.				
Saturday, 1st February	—	3,168,700	—	—
Sunday, 2nd February	—	3,318,900	—	—
Monday, 3rd February	—	3,781,100	—	—
Tuesday, 4th February	—	3,293,700	—	—
Wednesday, 5th February	—	3,456,100	—	—
Thursday, 6th February		2,950,000		—
Friday, 7th February	—	2,243,500	—	—
Saturday, 8th February	—	3,225,000	0·10	—
Sunday, 9th February	—	3,206,100	Uncertain.	—
Monday, 10th February	—	3,100,000	Uncertain.	—
Tuesday, 11th February	—	3,250,000	Uncertain.	—
Wednesday, 12th February	—	3,175,000	Uncertain.	—
Thursday, 13th February	—	2,662,300	Uncertain.	—
Friday, 14th February	—	2,687,400	—	—
Saturday, 15th February	—	2,437,300	—	—
Sunday, 16th February	—	2,525,000	—	—
Monday, 17th February	—	3,512,300	—	—
Tuesday, 18th February	—	2,881,200	—	—
Wednesday, 19th February	—	3,874,800	—	—
Thursday, 20th February	—	3,812,500	—	—
Friday, 21st February	—	3,581,000	—	—
Saturday, 22nd February	—	3,868,700	—	—
Sunday, 23rd February	—	3,749,800	0·07	—
Monday, 24th February	—	5,312,400	0·27	—
Tuesday, 25th February	—	4,699,500	0·02	—
Wednesday, 26th February	—	3,831,300	—	—
Thursday, 27th February	—	3,812,600	0·02	—
Friday 28th February	—	3,337,400	0·01	—

STOCKPORT CORPORATION—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1902—*continued.*				
Saturday, 1st March	—	2,737,300	—	—
Sunday, 2nd March	—	2,737,300	—	—
Monday, 3rd March	—	3,031,100	—	—
Tuesday, 4th March	—	3,193,800	—	—
Wednesday, 5th March	—	2,868,600	—	—
Thursday, 6th March	—	2,906,100	—	—
Friday, 7th March	—	3,587,200	—	—
Saturday, 8th March	—	4,031,000	·15	—
Sunday, 9th March	—	3,400,000	·05	—
Monday, 10th March	—	3,950,000	·11	—
Tuesday, 11th March	—	3,525,000	—	—
Wednesday, 12th March	—	2,725,000	—	—
Thursday, 13th March	—	3,512,300	·05	—
Friday, 14th March	—	4,012,400	·10	—
Saturday, 15th March	—	3,793,700	·04	—
Sunday, 16th March	—	2,237,200	—	—
Monday, 17th March	—	3,406,100	·01	—
Tuesday, 18th March	—	3,187,400	—	—
Wednesday, 19th March	—	3,568,500	·07	—
Thursday, 20th March	—	3,787,300	·09	—
Friday, 21st March	—	3,200,000	·03	—
Saturday, 22nd March	—	2,824,800	·03	—
Sunday, 23rd March	—	2,656,100	·03	—
Monday, 24th March	—	4,625,000	·12	—
Tuesday, 25th March	—	4,581,100	·10	—
Wednesday, 26th March	—	4,556,000	·14	—
Thursday, 27th March	—	4,656,000	·10	—
Friday, 28th March	—	3,425,000	·06	—
Saturday, 29th March	—	2,900,000	·01	—
Sunday, 30th March	—	2,562,200	—	—
Monday, 31st March	—	3,987,900	·09	—

STOCKTON CORPORATION—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1902—*continued.*				
Tuesday, 1st April	—	4,250,200	·10	—
Wednesday, 2nd April	—	3,181,500	—	—
Thursday, 3rd April	—	4,281,100	·15	—
Friday, 4th April	—	5,263,000	·12	—
Saturday, 5th April	—	6,068,200	·38	2½ times av. D.W. volume.
Sunday, 6th April	—	3,375,000	—	—
Monday, 7th April	—	3,519,000	—	—
Tuesday, 8th April	—	3,300,000	—	—
Wednesday, 9th April	—	3,081,300	—	—
Thursday 10th April	—	3,043,900	—	—
Friday, 11th April	—	3,256,200	—	—
Saturday, 12th April	—	3,106,200	·02	—
Sunday, 13th April	—	3,187,800	·13	—
Monday, 14th April	—	3,262,500	—	—
Tuesday, 15th April	—	5,956,000	·45	—
Wednesday, 16th April	—	3,931,100	·06	—
Thursday, 17th April	—	3,300,000	—	—
Friday, 18th April	—	3,025,000	—	—
Saturday, 19th April	—	3,212,500	·01	—
Sunday, 20th April	—	3,537,400	·19	—
Monday, 21st April	—	3,237,500	·01	—
Tuesday, 22nd April	—	4,156,500	·08	—
Wednesday, 23rd April	—	2,693,800	—	—
Thursday, 24th April	—	2,806,300	·01	—
Friday, 25th April	—	3,050,000	—	—
Saturday, 26th April	—	2,568,800	—	—
Sunday, 27th April	—	2,531,400	—	—
Monday, 28th April	—	3,275,000	—	—
Tuesday, 29th April	—	3,200,000	—	—
Wednesday, 30th April	—	3,156,500	·11	—

Stockport Corporation.—Pumping Figures—*continued.*

Date.	Total Discharge per 24 hours.		Rainfall.	Remarks.
	Cubic Feet.	Gallons.	Inches.	
1902—*continued.*				
Thursday, 1st May	—	2,531,300	·05	—
Friday, 2nd May	—	3,181,400	·13	—
Saturday, 3rd May	—	3,575,000	·36	—
Sunday, 4th May	—	3,025,000	·07	—
Monday, 5th May	—	3,256,000	·10	—
Tuesday, 6th May	—	3,475,000	06	—
Wednesday, 7th May	—	3,581,200	·01	—
Thursday, 8th May	—	2,512,600	—	—
Friday, 9th May	—	3,237,300	12	—
Saturday, 10th May	—	2,418,800	—	—
Sunday, 11th May	—	2,250,000	—	—
Monday, 12th May	—	2,462,500	—	—
Tuesday, 13th May	—	2,631,300	—	—
Wednesday, 14th May	—	2,493,700	·03	—
Thursday, 15th May	—	4,400,000	·35	—
Friday, 16th May	—	4,812,500	·20	—
Saturday, 17th May	—	4,369,000	·43	—
Sunday, 18th May	—	4,681,000	·12	—
Monday, 19th May	—	3,975,000	—	—
Tuesday, 20th May	—	2,787,300	·09	—
Wednesday, 21st May	—	2,900,000	—	—
Thursday, 22nd May	—	6,237,000		—
Friday, 23rd May	—	4,312,300	·40	—
Saturday, 24th May	—	2,693,700	·06	—
Sunday, 25th May	—	2 543,800	—	—
Monday, 26th May	—	2,700,000	·02	—
Tuesday, 27th May	—	2,900,000	—	—
Wednesday, 28th May	—	2,906,200	·04	—
Thursday, 29th May	—	2,687,400	·05	—
Friday, 30th May	—	3,025,000	06	—
Saturday, 31st May	—	2,137,300	—	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1902—*continued.*				
Sunday, 1st June	—	2,625,000	0·05	—
Monday, 2nd June	—	2,887,500	0·04	—
Tuesday, 3rd June	—	2,568,700	—	—
Wednesday, 4th June	—	2,800,000	0·01	—
Thursday, 5th June	—	3,106,100	0·08	—
Friday, 6th June	—	3,393,700	0·07	—
Saturday, 7th June	—	4,825,000	0·19	—
Sunday, 8th June	—	2,493,700	—	—
Monday, 9th June	—	3,200,000	—	—
Tuesday, 10th June	—	2,868,500	—	—
Wednesday, 11th June	—	3,062,500	0·03	—
Thursday, 12th June	—	3,050,000	0·06	—
Friday, 13th June	—	2,793,600	0·02	—
Saturday, 14th June	—	2,812,400	0·04	—
Sunday, 15th June	—	2,325,000	—	—
Monday, 16th June		2,743,700	—	—
Tuesday, 17th June	—	3,343,800	0·10	—
Wednesday, 18th June		2,483,600	—	—
Thursday, 19th June	—	2,781,200	—	—
Friday 20th June	—	4,518,400	0·19	—
Saturday, 21st June	—	2,337,300	0·01	—
Sunday, 22nd June	—	2,781,200	0·08	—
Monday, 23rd June	—	2,906,200	—	—
Tuesday, 24th June	—	3,343,800	—	—
Wednesday, 25th June	—	3,950,000	—	—
Thursday, 26th June	—	2,306,200	—	—
Friday, 27th June	—	3,168,900	—	—
Saturday, 28th June	—	3,025,000	—	—
Sunday, 29th June	—	2,668,600	—	—
day 30th June	—	3,424,900	—	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1902—*continued.*				
Tuesday, 1st July	—	4,287,500	·11	Reddish sewage connected.
Wednesday, 2nd July	—	2,981,200	—	—
Thursday, 3rd July	—	3,062,700	—	—
Friday, 4th July	—	3,425,000	·02	—
Saturday, 5th July	—	3,100,000	—	—
Sunday, 6th July	—	2,744,000	—	—
Monday, 7th July	—	3,037,800	—	—
Tuesday, 8th July	—	3,381,500	·01	—
Wednesday, 9th July	—	4,281,300	·10	—
Thursday, 10th July	—	4,981,400	·38	—
Friday, 11th July	—	3,069,000	·01	—
Saturday, 12th July	—	2,819,000	—	—
Sunday, 13th July	—	2,556,400	—	—
Monday, 14th July	—	2,812,600	—	—
Tuesday, 15th July	—	3,131,300	—	—
Wednesday, 16th July	—	3,319,000	—	—
Thursday, 17th July	—	2,662,700	—	—
Friday, 18th July	—	2,862,500	—	—
Saturday, 19th July	—	2,756,700	—	—
Sunday, 20th July	—	2,612,800	—	—
Monday, 21st July	—	3,825,700	·15	—
Tuesday, 22nd July	—	4,863,000	·16	—
Wednesday, 23rd July	—	3,419,000	·04	—
Thursday, 24th July	—	2,994,000	·02	—
Friday, 25th July	—	3,188,000	—	—
Saturday, 26th July	—	4,869,400	·41	—
Sunday, 27th July	—	2,750,300	·03	—
Monday, 28th July	—	2,919,000	·01	—
Tuesday, 29th July	—	3,050,200	·03	—
Wednesday, 30th July	—	2,950,100	—	—
Thursday, 31st July	—	2,706,300	—	—

STOCKPORT CORPORATION.—Pumping Figures.—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubit feet.	Gallons.	Inches.	
1902—*continued.*				
Friday, 1st August - - -	—	2,944,000	—	—
Saturday, 2nd August- - -	—	4,956,300	·31	—
Sunday, 3rd August - - -	—	4,056,400	·17	—
Monday, 4th August - - -	—	2 650,300	·09	—
Tuesday, 5th August - - -	—	2,987,500	—	—
Wednesday, 6th August - -	—	4,982.400	·23	—
Thursday, 7th August - -	—	4,044,000	·24	—
Friday, 8th August - - -	—	3,650,000	·09	—
Saturday, 9th August - - -	—	2,962,500	·09	—
Sunday, 10th August - - -	—	3 062,600	·13	—
Monday, 11th August - - -	—	2,962,500	·01	—
Tuesday, 12th August - -	—	3,137,200	·07	—
Wednesday, 13th August - -	—	3,193,700	·04	—
Thursday, 14th August - -	—	2,756,200	—	—
Friday, 15th August - - -	—	2,900,000	—	—
Saturday, 16th August - -	—	2,937,300	—	—
Sunday, 17th August - - -	—	4,563,000	·41	—
Monday, 18th August - - -	—	3,513,000	·23	—
Tuesday, 19th August- - -	—	4,093,900	·09	—
Wednesday, 20th August - -	—	2,631,600	·07	—
Thursday, 21st August - -	—	2,090,400	—	—
Friday, 22nd August - - -	—	3,437.600	·10	—
Saturday, 23rd August - -	—	4,431,600	·28	—
Sunday, 24th August - - -	—	2,506,500	—	—
Monday, 25th August - - -	—	3,387,800	·02	—
Tuesday, 26th August- - -	—	3,081,50	—	—
Wednesday, 27th August - -	—	3,688,000	·11	—
Thursday, 28th August - -	—	3,056,500	—	—
Friday, 29th August - - -	—	3,375,200	·04	—
Saturday, 30th August - -	—	2,612,800	—	—
Sunday, 31st - - - -	—	2,844,000	·02	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic Feet.	Gallons.	Inches.	
1902—*continued.*				
Monday, 1st September - -	—	3,262,900	—	—
Tuesday, 2nd September - -	—	3,744,000	—	—
Wednesday, 3rd September -	—	3,881 500	·06	—
Thursday 4th September - -	—	2,850,000	·14	—
Friday, 5th September - -	—	3,331 600	—	—
Saturday, 6th September - -	—	2,881,700	—	—
Sunday, 7th September - -	—	2,587,700	—	—
Monday, 8th September - -	—	2,781,600	—	—
Tuesday, 9th September - -	—	3,075,100	—	—
Wednesday, 10th September -	—	4,100,000	·08	—
Thursday, 11th September - -	—	3,256,400	·13	—
Friday, 12th September - -	—	3,262,800	·05	—
Saturday, 13th September - -	—	2,712,800	—	—
Sunday, 14th September - -	—	2,712,800	·03	—
Monday, 15th September - -	—	2,950,100	·01	—
Tuesday, 16th September - -	—	3,657,000	·07	—
Wednesday, 17th September -	—	4,119,000	·15	—
Thursday, 18th September - -	—	2,875,100	—	—
Friday, 19th September - -	—	2,800,000	—	—
Saturday, 20th September -	—	2,869,000	—	—
Sunday, 21st September - -	—	2,413,000	—	—
Monday, 22nd September - -	—	3,556,400	·11	—
Tuesday, 23rd September - -	—	3,938,000	·12	—
Wednesday, 24th September -	—	3,075,100	—	—
Thursday, 25th September - -	—	2,875,200	—	—
Friday, 26th September - -	—	2,862.800	—	—
Saturday, 27th September - -	—	3,019,100	—	—
Sunday, 28th September - -	—	2,337,600	—	—
Monday, 29th September - -	—	3,081,400	—	—
Tuesday, 30th September - -	—	2,888,000	—	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic Feet.	Gallons.	Inches.	
1902—*continued.*				
Wednesday, 1st October	—	2,888,000	—	——
Thursday, 2nd October	—	3,050,100	·03	——
Friday, 3rd October	—	3,269,000	·05	——
Saturday, 4th October	—	2,800,000	—	——
Sunday, 5th October	—	2,300,000	—	——
Monday, 6th October	—	2,987,500	—	——
Tuesday, 7th October	—	3,069,000	—	——
Wednesday, 8th October	—	2,769,000	—	——
Thursday, 9th October	—	5,257,000	·50	——
Friday, 10th October	—	5,606,700	·18	——
Saturday, 11th October	—	3,244,000	·01	——
Sunday, 12th October	—	2,919,000	—	——
Monday, 13th October	—	6,782,000	·42	——
Tuesday, 14th October	—	8,408,000	·63	2¾ times average D. W. volume.
Wednesday, 15th October	—	6,732,000	·24	——
Thursday, 16th October	—	8,438,000	·26	3 times average D. W. volume.
Friday, 17th October	—	8,302,000	·18	2¾ times average D. W. volume.
Saturday, 18th October	—	7,113,000	·14	2½ times average D. W. volume.
Sunday, 19th October	—	3,931,000	—	——
Monday, 20th October	—	6,150,000	·17	——
Tuesday, 21st October	—	3,912,500	·01	——
Wednesday, 22nd October	—	7,239,000	·19	——
Thursday, 23rd October	—	4,319,000	·02	——
Friday, 24th October	—	3,775,000	—	——
Saturday, 25th October	—	3,369,000	—	——
Sunday, 26th October	—	3,881,000	·15	——
Monday, 27th October	—	3,531,200	—	——
Tuesday, 28th October	—	3,237,400	—	——
Wednesday, 29th October	—	3,468,900	—	——
Thursday, 30th October	—	3,306,200	—	——
Friday, 31st October	—	3,356,400	·02	——

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic Feet.	Gallons.	Inches.	
1902—*continued.*				
Saturday, 1st November	—	3,056,200	—	—
Sunday, 2nd November	—	2,712,400	—	—
Monday, 3rd November	—	3 193,900	—	—
Tuesday, 4th November	—	3,218,500	·02	—
Wednesday, 5th November	—	3,175,000	·03	—
Thursday, 6th November	—	3,375,000	·02	—
Friday, 7th November	—	3,162,600	·01	—
Saturday, 8th November	—	5 068,800	·33	—
Sunday, 9th November	—	4,100,000	·06	—
Monday, 10th November	—	3,581,000	·05	—
Tuesday, 11th November	—	3,987,500	·07	—
Wednesday, 12th November	—	3,225,000	—	—
Thursday, 13th November	—	2,925,000	—	—
Friday, 14th November	—	3,262,500	·05	—
Saturday, 15th November	—	2,850,000	—	—
Sunday, 16th November	—	2,306,200	—	—
Monday, 17th November	—	2,756,300	—	—
Tuesday, 18th November	—	2,756,300	—	—
Wednesday, 19th November	—	2,806,200	—	—
Thursday, 20th November	—	2,725,000	—	—
Friday, 21st November	—	2,706,200	—	—
Saturday, 22nd November	—	2,787,400	·03	—
Sunday, 23rd November	—	2,562,400	·01	—
Monday, 24th November	—	3,800,000	·11	—
Tuesday, 25th November	—	3,381 200	·01	—
Wednesday, 26th November	—	3,268,700	·02	—
Thursday, 27th November	—	2,243,800	·03	—
Friday, 28th November	—	5,512,700	·31	—
Saturday, 29th November	—	4,300,000	·01	—
Sunday, 30th November	—	2,925,000	—	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic Feet.	Gallons.	Inches.	
1902—*continued.*				
Monday, 1st December - -	—	4,781,300	·21	——
Tuesday, 2nd December - -	—	8,476,000	·36	2¾ times average D. W. volume.
Wednesday, 3rd December - -	—	6,075,000	·07	——
Thursday, 4th December - -	—	3,412,500	—	——
Friday, 5th December - -	—	3,319,000	—	——
Saturday, 6th December - -	—	2,781,200	—	——
Sunday, 7th December - -	—	2,393,900	—	——
Monday, 8th December - -	—	2,843,800	—	——
Tuesday, 9th December - -	—	2,793,900	—	——
Wednesday, 10th December -	—	3,143,800	—	——
Thursday, 11th December - -	—	2,762,500	—	——
Friday, 12th December - -	—	2,687,400	—	——
Saturday, 13th December	—	2,856,200	·03	——
Sunday, 14th December - -	—	2,506,200	·01	——
Monday, 15th December - -	—	4,731,000	·15	——
Tuesday, 16th December - -	—	8,213,500	·42	2⅓ times average D. W. volume.
Wednesday, 17th December -	—	7,688,600	·04	2½ times average D. W. volume.
Thursday, 18th December - -	—	6,870,000	·19	2½ times average D. W. volume.
Friday, 19th December - -	—	4,850,000	·03	——
Saturday, 20th December - -	—	3,637,800	—	——
Sunday, 21st December - -	—	3,019,000	—	——
Monday, 22nd December - -	—	3,637,600	·01	——
Tuesday, 23rd December - -	—	3,612,300	—	——
Wednesday, 24th December -	—	3,312,600	—	——
Thursday, 25th December - -	—	2,612,500	—	——
Friday, 26th December - -	—	3,531,100	·02	——
Saturday, 27th December - -	—	2,912,600	—	——
Sunday, 28th December - -	—	4,613,000	·18	——
Monday, 29th December - -	—	3,856,200	—	——
Tuesday, 30th December - -	—	4,506,000	·10	——
Wednesday, 31st December -	—	3,350,000	—	——

STOCKPORT CORPORATION—Pumping Figures—*continued.*

DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1903.				
Thursday, 1st January	—	3,325,100	–	—
Friday, 2nd January	—	5,037,700	·17	—
Saturday, 3rd January	—	5,212,000	·07	—
Sunday, 4th January	—	3,412,500	·01	—
Monday, 5th January	—	7,051,000	·36	—
Tuesday, 6th January	—	8,382,700	·15	2¾ times av. D.W. volume.
Wednesday, 7th January	—	8,182,000	·23	2¾ times av. D.W. volume.
Thursday, 8th January	—	7,713,000	·04	2¾ times av. D.W. volume.
Friday, 9th January	—	6,307,500	·05	—
Saturday, 10th January	—	8,251,000	·19	3 times av. D.W. volume.
Sunday, 11th January	—	4,400,000	—	—
Monday, 12th January	—	3,814,000	—	—
Tuesday, 13th January	—	3,806,300	—	—
Wednesday, 14th January	—	3,537,500	—	—
Thursday, 15th January	—	3,218,800	—	—
Friday, 16th January	—	2,800,000	—	—
Saturday, 17th January	—	2,756,400	—	—
Sunday, 18th January	—	2,462,300	—	—
Monday, 19th January	—	3,118,700	—	—
Tuesday, 20th January	—	3,300,000	—	—
Wednesday, 21st January	—	3,281,100	—	—
Thursday, 22nd January	—	4,206,500	18	—
Friday, 23rd January	—	3,669,000	0·02	—
Saturday, 24th January	—	6,006,500	·15	—
Sunday, 25th January	—	3,162,500	01	—
Monday, 26th January	—	3,625,000	01	—
Tuesday, 27th January	—	6,413,200	·19	—
Wednesday, 28th January	—	5,556,100	—	—
Thursday, 29th January	—	3,606,000	—	—
Friday, 30th January	—	3,325,000	—	—
Saturday, 31st January	—	3,156,200	·01	—

STOCKPORT CORPORATION.—Pumping Figures—*continued.*

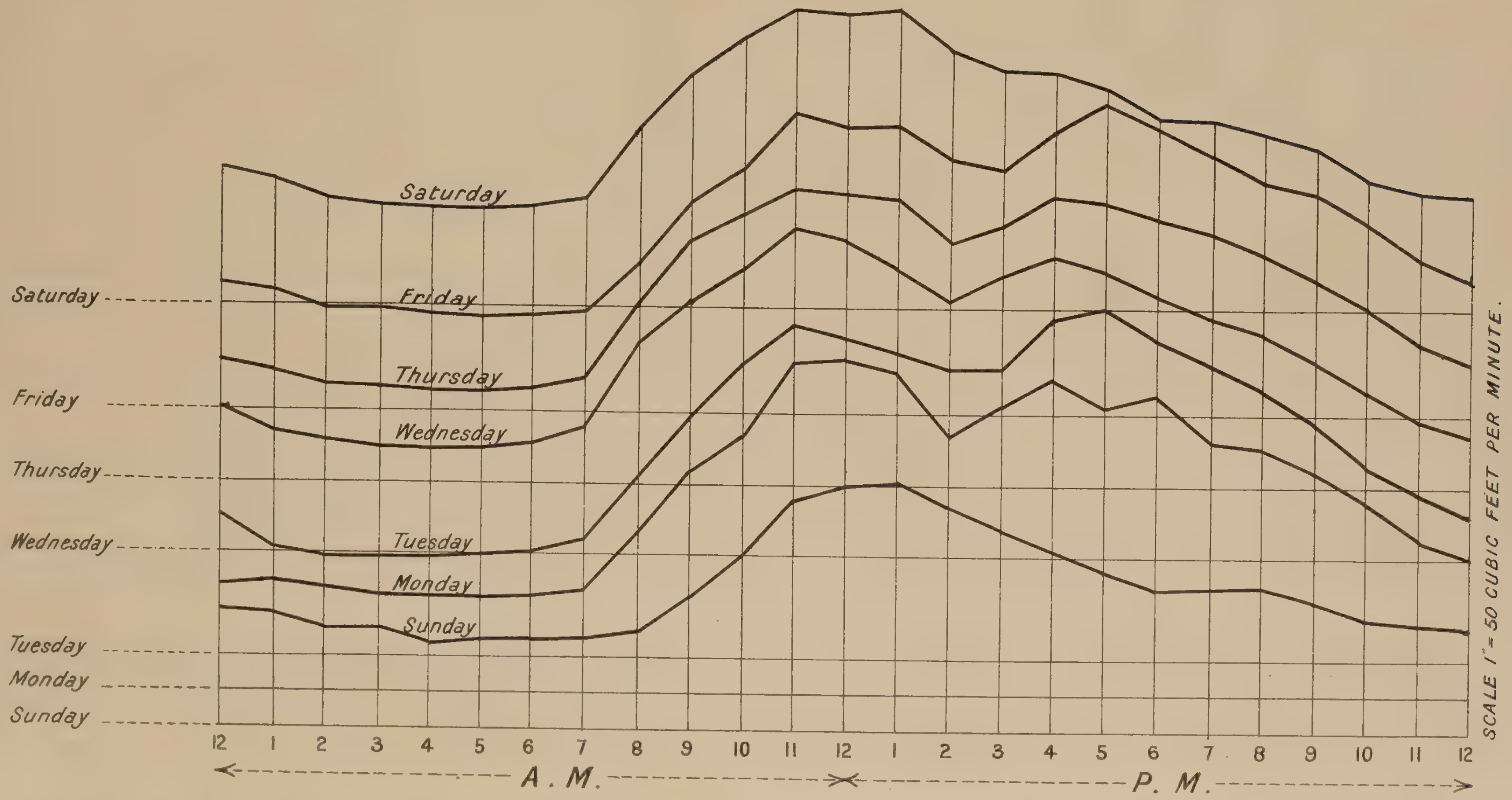
DATE.	Total Discharge per 24 hours.		Rainfall.	REMARKS.
	Cubic feet.	Gallons.	Inches.	
1903—*continued.*				
Sunday, 1st February - - -	—	3,912,400	·07	—
Monday, 2nd February - -	—	3,571,900	·10	—
Tuesday, 3rd February - -	—	4,425,000	·03	—
Wednesday, 4th February - -	—	4,050,000	·01	—
Thursday, 5th February - -	—	3,937,300	·01	—
Friday, 6th February - -	—	3,712,700	·01	—
Saturday, 7th February - -	—	4,225,000	·05	—
Sunday, 8th February - -	—	3,125,000	—	—
Monday, 9th February - -	—	5,112,100	·08	—
Tuesday, 10th February - -	—	3,712,500	—	—
Wednesday, 11th February	—	4,256,100	·02	—
Thursday, 12th February - -	—	4,037,700	·03	—
Friday, 13th February - -	—	3,850,000	·01	—
Saturday, 14th February - -	—	3,456,200	·02	—
Sunday, 15th February - -	—	3,581,100	—	—
Monday, 16th February - -	—	3,775,000	—	—
Tuesday, 17th February - -	—	4,194,000	·01	—
Wednesday, 18th February -	—	3,425,000	—	—
Thursday, 19th February - -	—	3,494,000	—	—
Friday, 20th February - -	—	3,569,000	—	—
Saturday, 21st February - -	—	6,200,000	·30	Storm Samples.
Sunday, 22nd February - -	—	6,826,000	·07	2¾ times av. D. W. volume.
Monday, 23rd February - -	—	5,925,000	·06	—
Tuesday, 24th February - -	—	5,931,200	·07	—
Wednesday, 25th February -	—	9,000,000	·25	3 times av. D. W. volume.
Thursday, 26th February - -	—	7,814,000	·03	2¾ times av. D. W. volume.
Friday, 27th February - -	—	4,863,000	·03	—
Saturday, 28th February - -	—	4,537,500	·04	—

A.

MACCLESFIELD OUTFALL SEWER GAUGINGS.

AVERAGE HOURLY DRY WEATHER FLOW, IN THE YEAR 1902.

CUBIC FEET PER MINUTE.



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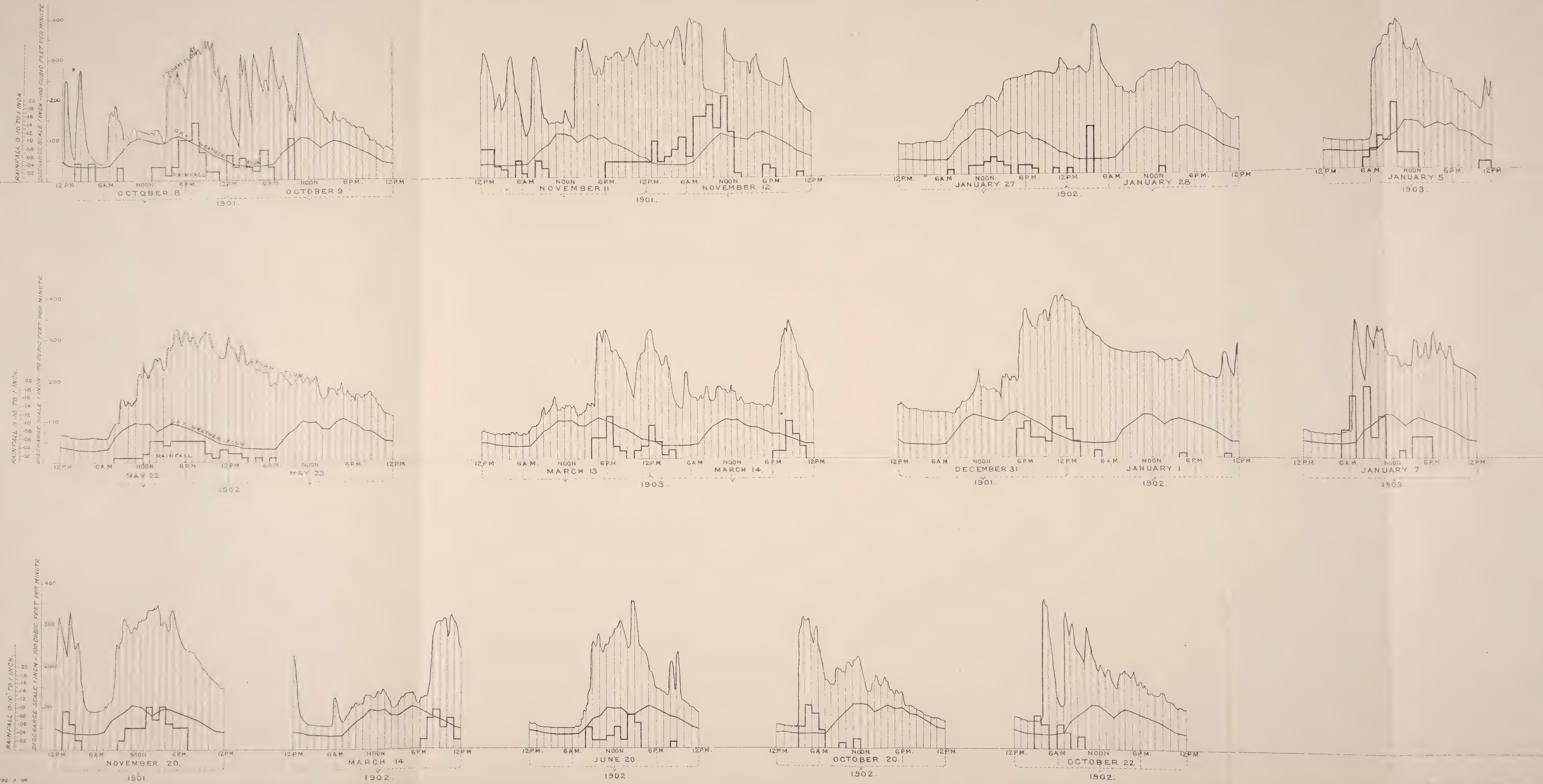
ROYAL COMMISSION ON SEWAGE DISPOSAL.

B

MACCLESFIELD SEWAGE DIAGRAMS SHOWING STORM FLOW.



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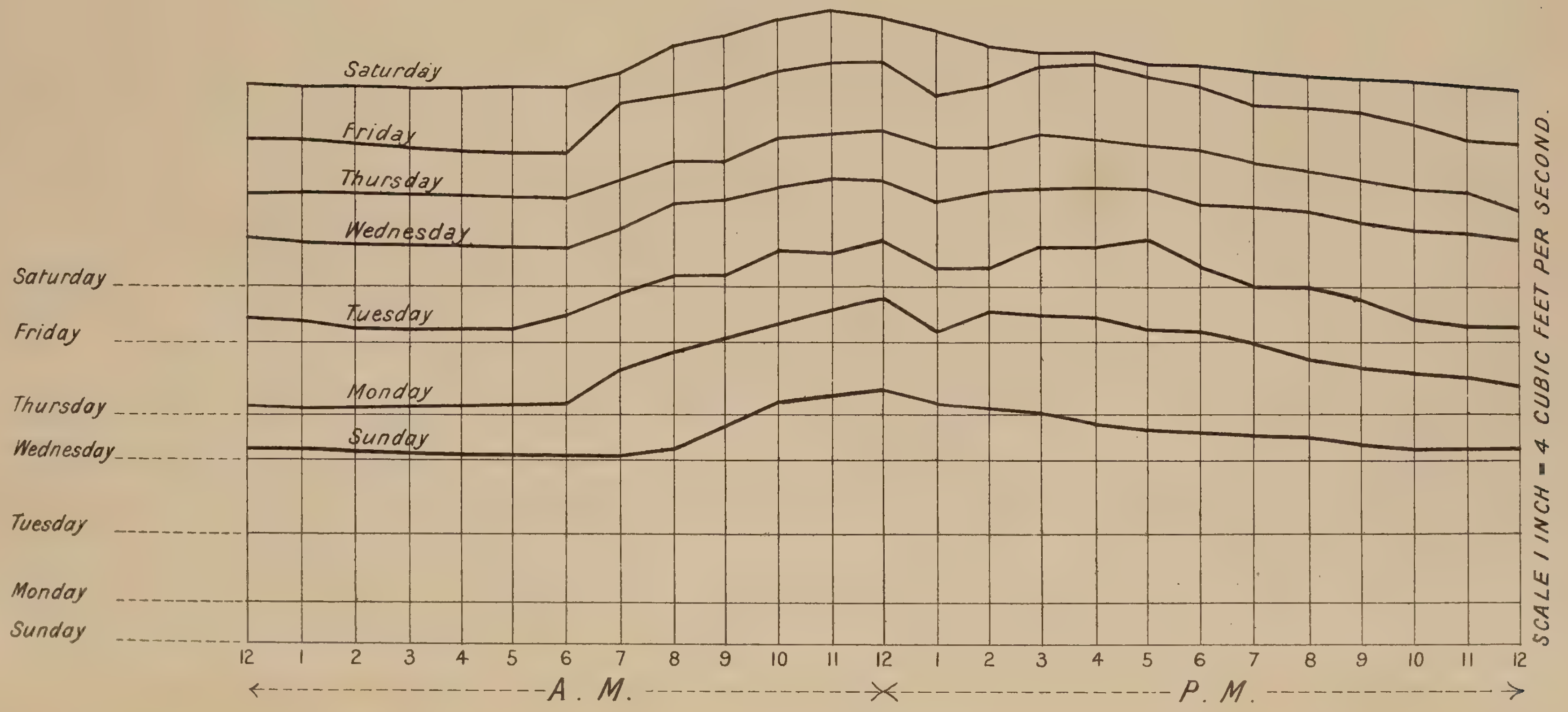
ROYAL COMMISSION ON SEWAGE DISPOSAL.

C.

ROCHDALE OUTFALL SEWER GAUGINGS.

AVERAGE HOURLY DRY WEATHER FLOW IN THE YEAR 1902.

CUBIC FEET PER SECOND.



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ADDENDUM 1 TO MR. TATTON'S REPORT.

RESULTS OF THE BACTERIOLOGICAL EXAMINATION OF SAMPLES OF MACCLESFIELD, ROCHDALE, AND STOCKPORT SEWAGES, DILUTED WITH STORM WATER.

A. C. HOUSTON.

July 24, 1904.

RESULTS OF THE BACTERIOLOGICAL EXAMINATION

1						2		3						4			
Description of the sample						Total Number of Bacteria in 1 c.c.		Number of B. Coli (or closely allied forms) in 1 c.c. (Primary broth cultures (48 hours at 37° C.) and subsequent surface gelatine plate method).						Chief Biological Characters of the *strain* of B. Coli present in the number specified in Col. 3.			
No.	Time of Collection.				Other Details.									Gas.	Indol.	(a) Acidity. (b) Clot. (Litmus milk cultures, 5 days at 37° C.)	
	Hour.	Day.	Month.	Year.		Gelatine at 20 C°.	Agar at 37 C°.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	10,000 ·0001 c.c.	100,000 ·00001 c.c.	(Gelatine "shake" cultures, 24 hrs. at 20° C.)	(Broth cultures, 5 days at 37° C.)	(a)	(b)
1 ..	12.30 p.m.	6	10	1901	3 times diluted by storm water												
2 ..	12.50 p.m.	6	10	1901	4 times diluted by storm water												
3 ..	2.30 p.m.	6	10	1901	3 times diluted by storm water												
4 ..	2 p.m.	12	11	1901	4 times diluted by storm water	31,700,000	5,460,000						+				
5 ..	2.30 p.m.	12	11	1901	3 times diluted by storm water												
6 ..	3.15 p.m.	12	11	1901	3½ times diluted by storm water												
7 ..	2 p.m.	4	1	1902	4½ times diluted by storm water	11,500,000	390,000						+	+	—	+	—
8 ..	3 p.m.	4	1	1902	4 times diluted by storm water	11,600,000	300,000						+	+	—	+	—
9 ..	4 p.m.	4	1	1902	3½ times diluted by storm water	8,900,000	550,000						+	+	+	+	+
10 ..	2.45 p.m.	1	7	1902	3 times diluted by storm water								+	+	+	+	+
11 ..	3 p.m.	1	7	1902	4 times diluted by storm water								+	+	+	+	+
12 ..	3.15 p.m.	1	7	1902	6 times diluted by storm water								+	+	+	+	+
13 ..	4 p.m.	1	7	1902	3 times diluted by storm water								+	+	+	+	+
14 ..	2.30 p.m.	10	7	1902	3 times diluted by storm water												
15 ..	1.15 p.m.	10	7	1902	4 times diluted by storm water												
16 ..	12 noon	10	7	1902	5 times diluted by storm water												
17 ..	3.30 p.m.	7	1	1903	4½ times diluted by storm water							+	—	+	+	+	+
					AVERAGES:	15,925,000	1,675,000	1 sample at 10,000 per c.c. 8 „ „ 100,000 per c.c.						6 out of 8, both indol and clot 2 out of 8, neither indol nor clot			

of Macclesfield Storm Sewage.

5						6						7						8						9
Indol Test. Indol in broth cultures direct. (5 days at 37° C).						B. Enteritidis Sporogenes Test. Spores of B. enteritidis. sporogenes (Klein's "enteritidis change" in anærobic milk cultures): Cultures heated to 80° C. for 10 minutes.						"Gas" Test. "Gas" production in gelatine 'shake' cultures, 24 hours at 20° C.						B.S. = Bile-salt glucose peptone test. N.R. = Neutral-red broth test. L.P.M. = Lactose peptone milk test.						REMARKS.
1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	
1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	
								+	—						+	—							N.R. +	
									+	—					+	—							N.R +	
								+	—						+	—							N.R. +	
					+			+	—						+	—							N.R. +	During the 24 hours preceding the taking of these samples the sewage had been continuously diluted by rain water; for a short period the dilution amounted to as much as six times.
								+	—						+	—							N.R. +	
									+	—					+	—							N.R. +	
				+	—			+	—						+	—						N R. +	—	
				+	—		+	—						+	—							N R. +	—	
					+			+	—					+	—							N.R. +	—	
					+				+	—						+						N.R B.S L·P.M	+	
				+	—				+	—						+						N.R. B.S. L P.M.	+	
				+	—					+					+	—						N.R B.S L.P.M.	+	
				+	—			+	—						+	—						N.R. B.S. L.P.M.	+	
									+	—												L P M. +	B.S. +	
								+	—														B S. + L.P.M.	
								+	—														B.S. + L.P.M.	
					+			+	—					+	—							B.S. + N.R.	L.P.M +	Previous to sample being taken the sewage flow had been diluted 3 times and upwards for 9 hours.
5 samples at 10,000 } per 4 „ „ 100,000 } c.c.						1 sample at 10 } per c.c. 10 „ „ 100 5 „ „ 1,000 1 „ „ 10,000						Usually + ·001; — ·0001 c.c. (gelatine at 20° C.)						Neutral-red broth test; 4 samples at 10,000 } per 10 „ „ 100,000 } c.c. Bile salt glucose peptone test; 1 sample at 10,000 } per 7 „ „ 100,000 } c.c. Lactose peptone milk test: 1 sample at 10,000 } per 7 „ „ 100,000 } c.c.						

RESULTS OF THE BACTERIOLOGICAL EXAMINATION

1						2		3						4			
Description of the Sample.						Total Number of Bacteria in 1 c.c.		Number of B. Coli (or closely allied forms) in 1 c.c. (Primary broth cultures (48 hours at 37° C.) and subsequent surface gelatine plate method).						Chief Biological Characters of the *strain* of B. Coli present in the number specified in Col. 3.			
No.	Time of Collection.				Other Details.	Gelatine at 20 C°.	Agar at 37 C°.	1	10	100	1,000	10,000	100,000	Gas. (Gelatine "shake" cultures, 24 hrs. at 20° C.)	Indol. (Broth cultures, 5 days at 37° C.)	(a) Acidity. (b) Clot. (Litmusmilk cultures, 5 days at 37° C.)	
	Hour.	Day.	Month.	Year.				1 c.c.	·1 c.c.	·01 c.c	·001 c.c.	·0001 c.c.	·00001 c.c.			(a)	(b)
1 ..	3.30 p.m.	4	4	1902	Three times diluted by storm water ..	16,100,000	1,680,000					+	—	+	+	+	+
2 ..	3.15 p.m.	5	4	1902	Five times diluted by storm water ..	2,600,000	270,000					+	—	+	—	+	+
3 ..	4.15 p.m.	5	4	1902	Seven times diluted by storm water ..	5,200,000	340,000					+	—	+	+	alk.	—
4 ..	3.0 p.m.	2	5	1902	Three times diluted by storm water ..	17,600,000	860,000						+	+	+	+	+
5 ..	3.30 p.m.	2	5	1902	Four times diluted by storm water ..	34,600,000	2,200,000						+	+	+	+	+
6 ..	1.40 p.m.	2	5	1902	Six times diluted by storm water ..	21,100,000	2,770,000						+	+	+	+	+
7 ..	2.5 p.m.	2	5	1902	Five times diluted by storm water ..	76,500,000	1,540,000					+	—	+	+	+	+
8 ..	1.0 p.m.	10	10	1902	Three times diluted by storm water ..	18,600,000	3,040,000						+	+	+	+	+
9 ..	12 noon	5	1	1903	Three times diluted by storm water ..								+	+	+	+	+
10 ..	2 p.m.	5	1	1903	Five times diluted by storm water ..								+	+	+	+	+
11 ..	3.10 p.m.	5	1	1903	Six times diluted by storm water ..								+	+	—	+	+
AVERAGES:						24,037,500	1,587,500	4 samples at 10,000 7 samples at 100,900 } per c.c.						8 out of 11, both indol and clot 2 out of 11, clot, but no indol 1 out of 11, indol, but no clot			

OF SAMPLES OF ROCHDALE STORM SEWAGES.

Indol Test. Indol in broth cultures direct (5 days at 37° C).						B. Enteritidis Sporogenes Test. Spores of B. enteritidis sporogenes (Klein's "enteritidis change" in anærobic milk cultures). Cultures heated to 80° C. for 10 minutes.						"Gas" Test. "Gas" production in gelatin "shake" cultures, 24 hours at 20° C.						B.S. = Bile-salt glucose peptone test. N.R. = Neutral-red broth test. L.P.M. = Lactose peptone milk test.						REMARKS.
1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	
1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	
					+			+	−					+	−							N.R. B.S. L.P.M. }	+	
				+	−			+	−					+	−						LPM +	N.R. +	−	
				+	−			+	−					+	−						N.R. B.S. L.PM }	+	−	
					+				+	−													N.R. +	1 c.c. of broth cultures (48 hours at 37° C) each containing ·001 c.c. of storm waters 4, 5, and 7 was injected subcutaneously severally into three guinea-pigs (a, b and c). The guinea-pigs (a and b) recovered, but guinea-pig (c) died within 24 hours, and B. coli was isolated from its heart's blood. A fourth guinea-pig (d) inoculated with a broth culture representing ·01 c c. of sample 6 also died within 24 hours and B. coli was isolated from its heart's blood.
					+				+	−													N.R. +	
					+			+	−													N R. +	−	
				+	−			+	−														N.R. +	
					+			+	−						+	−						N.R. B.S. L.P.M. }	+	
					+			+	−					+	−							B.S. + L.P.M.	N.R. +	These samples were collected after the storm had continued for some time.
					+		+	−						+	−						LPM +	B.S. + N.R.	−	
					+		+	−						+	−							B.S. + L.P.M.	N.R. +	
3 samples at 10,000 „ „ 100,000 } per c c.						2 samples at 10 7 „ „ 100 2 „ „ 1,000 } per c.c.						Usually + ·01 ; − ·001 c.c. (24 hours at 20° C.)						Neutral-red broth test ; 4 samples at 10,000 7 „ „ 100,000 } per c.c. Bile-salt glucose peptone test : 4 samples at 10.000 2 „ „ 100,000 } per c.c. Lactose peptone milk test : 2 samples at 1,000 3 „ „ 10 000 2 „ „ 100,000 } per c.c.						

RESULTS OF THE BACTERIOLOGICAL EXAMINATION OF

1						2		3						4			
Description of the Sample.						Total Number of Bacteria in 1 c.c.		Number of B. Coli (or closely allied forms) in 1 c.c. (Primary broth cultures (48 hours at 37° C.) and subsequent surface gelatine plate method).						Chief Biological Characters of the *strain* of B. Coli present in the number specified in Col. 3.			
No.	Time of Collection.				Other Details.	Gelatine at 20 C°.	Agar at 37 C°.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c	1,000 ·001 c.c.	10,000 ·0001 c.c.	100,000 ·00001 c.c.	Gas. (Gelatine "shake" cultures, 24 hrs. at 20° C.)	Indol. (Broth cultures, 5 days at 37° C.)	(*a*) Acidity. (*b*) Clot. (Litmusmilk cultures, 5 days at 37° C)	
	Hour.	Day.	Month.	Year.												(*a*)	(*b*)
1 ..	—	24	8	1901	Crude sewage		4,360,000						+				
2 ..	—	26	8	1901	Storm sewage water, No. 1		9,760,000						+				
3 ..	—	26	8	1901	Storm sewage water, No. 2		6,200,000						+				
4 ..	—	26	8	1901	Storm sewage water, No. 3		5,600,000						+				
5 ..	4.45 p.m.	21	2	1903	Three times diluted by storm water ..	7,200,000							+	+	+	+	+
6 ..	5.30 p.m.	21	2	1903	Three times diluted by storm water ..	7,400,000						+	—	+	—	+	+
AVERAGES :						7,300,000	6,480,000	1 sample at 10,000 per 5 ,, 100,000 c.c.									

SAMPLES OF STOCKPORT STORM SEWAGE.

5						6						7						8						9
Indol Test. Indol in broth cultures direct (5 days at 37° C).						B. Enteritidis Sporogenes Test. Spores of B. enteritidis sporogenes (Klein's "enteritidis change" in anærobic milk cultures). Cultures heated to 80° C. for 10 minutes.						"Gas" Test. "Gas" production in gelatine "shake" cultures, 24 hours at 20° C.						B.S. = Bile-salt glucose peptone test. N.R. = Neutral-red broth test. L.P.M. = Lactose peptone milk test.						REMARKS.
1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	1	10	100	1,000	10,000	100,000	
1 .c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	1 c.c.	·1 c.c.	·01 c.c.	·001 c.c.	·0001 c.c.	·00001 c.c.	
					+			+	—															
					+			+	—															
					+			+	—															
					+		+	—																
					+				+	—				24 hrs. +	48 hrs. +	72 hrs. +	—					N.R. B.S. L.P.M.	} +	Previous to these samples (5 and 6) being taken the sewage was diluted 3 times the dry weather flow for a period of 13 hours. From a broth culture inoculated with ·01 c.c. of sample 6, B. pyocyaneus was isolated. A guinea-pig inoculated with 1 c.c. of a broth culture of this microbe died on the third day.
					+				+	—				24 hrs. +	48 hrs. +	72 hrs. +	—					N.R. + L.P.M.	B.S. +	
6 samples at 100,000 per c.c.						1 sample at 10 3 ,, ,, 100 2 ,, ,, 1,000 } per c.c.						+ ·01 ; — ·001 c.c. (24 hours at 20° C.)						Neutral-red broth test: 1 sample at 10,000 1 ,, ,, 100,000 } per c.c. Bile salt glucose peptone test: 2 samples at 100 000 per c.c. Lactose peptone milk test: 1 sample at 10,000 1 ,, ,, 100,000 } per c.c.						

SUMMARY OF RESULTS.*

TOTAL NUMBER OF BACTERIA.

——	Gelatine at 20° C.	Agar at 37° C.
Macclesfield - - - -	15,925,000	1,675,000
Rochdale - - - - -	24,037,500	1,587,500
Stockport - - - - -	7,300,000	6,480,000
AVERAGE - - - -	15,754,166	3,247,500

B. COLI TEST.

——	10,000	100,000
Macclesfield - - - -	1 sample.	8 samples.
Rochdale - - - - -	4 samples.	7 samples.
Stockport - - - - -	1 sample.	5 samples.
TOTAL - - - -	6 (about 23 per cent.).	20 (about 77 per cent.).

As regards the biological attributes of the B. coli (or coli-like microbes) isolated from the samples 15 out of 21 (about 71 per cent.) were, on the basis of the tests employed typical B. coli.

INDOL TEST.

——	10,000.	100,000.
Macclesfield - - - -	5 samples.	4 samples.
Rochdale - - - - -	3 samples.	8 samples.
Stockport - - - - -	——	6 samples.
TOTAL - - - -	8 (about 30 per cent.).	18 (about 69 per cent.).

---

* Unless otherwise stated the results are given as numbers of bacteria per c.c. of sample.

N.B.—As regards the B. coli, indol, neutral red broth, bile-salt glucose peptone, and lactose peptone milk tests, it should be noted that the tests were not "pushed" beyond $\frac{1}{100000}$ c.c.

B. ENTERITIDIS SPOROGENES TEST.

	10.	100.	1,000.	10,000.
Macclesfield - -	1 sample.	10 samples.	5 samples.	1 sample.
Rochdale -	2 samples.	7 samples.	2 samples.	—
Stockport - -	1 sample.	3 samples.	2 samples.	—
TOTAL - -	4 (about 11 %).	20 (about 59 %).	9 (about 26 %)	1 (about 3 %).

NEUTRAL RED BROTH TEST.

	10,000.	100,000.
Macclesfield - - - -	4 samples.	10 samples.
Rochdale - - - - -	4 samples.	7 samples.
Stockport - - - - -	1 sample.	1 sample.
TOTAL - - - -	9 (about 33 per cent.).	18 (about 66 per cent.).

BILE-SALT GLUCOSE PEPTONE TEST.

	10,000.	100,000.
Macclesfield - - - -	1 sample.	7 samples.
Rochdale - - - - -	4 samples.	2 samples.
Stockport - - - - -	—	2 samples.
TOTAL - - - -	5 (about 31 per cent.).	11 (about 69 per cent.).

LACTOSE PEPTONE MILK TEST.

	1,000.	10,000.	100,000.
Macclesfield - - -	—	1 sample.	7 samples.
Rochdale - - -	2 samples.	3 samples.	2 samples.
Stockport - - -	—	1 sample.	1 sample.
TOTAL - - -	2 (about 11 per cent.).	5 (about 29 per cent.).	10 (about 59 per cent.).

"GAS" TEST ("GAS" IN GELATINE "SHAKE" CULTURE WITHIN 24 HOURS AT 20° C.).

Macclesfield Rochdale Stockport	Nearly all the samples yielded a positive result with from ·01 to ·001 c.c.

GENERAL REMARKS.

The results show that storm sewages even when the dilution is considerable, and the samples are collected some considerable time after the commencement of storm, may be most impure bacteriologically.

From the bacteriological point of view, and in relation to the possible discharge of liquids of this sort into drinking water streams, it would seem unwise to consider storm sewages as much if any purer than the dry weather flow of sewage.

It needs to be remembered that the mere dilution of one volume of sewage even with five or more volumes of sterile water would leave the mixed liquid grossly impure from the bacteriological point of view. As a matter of fact there is evidence showing that the diluting liquid by the time it reaches the sewers is *per se* objectionable.

Moreover, even if it be granted that storm sewages may be purer bacteriologically than the dry weather flow of sewage, their increased volume must be taken into consideration.

The adequate treatment of storm sewages may be a difficult if not an impossible task. Hence some may consider stringent standards in relation to the dry weather flow of sewage out of place. Nevertheless, the dry weather flow of sewage is a constant, and the flow during storms only an occasional source of pollution.

The effect on a river water of allowing untreated sewage (even when diluted six or more times) to discharge into it is imperfectly known.

From the bacteriological point of view the problem is complex even if the simple case be taken of a river of average purity receiving the sewage from a single town.

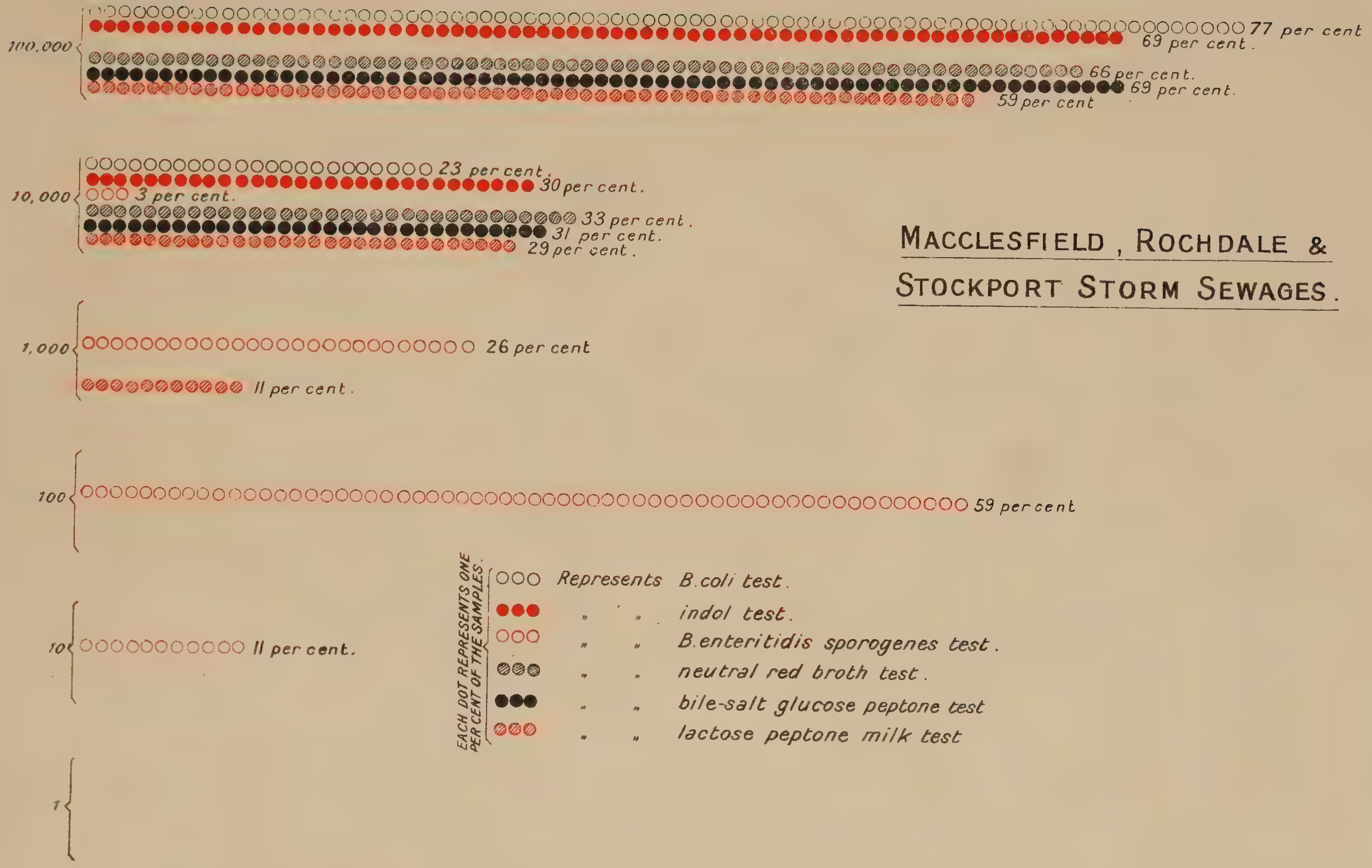
During a storm the river above the point of discharge of the storm outfalls is of larger volume than normal, but it may be more impure per unit of volume due to the "washings" of cultivated soils, etc.

Further, if the sewage be more dilute during storms it is also of larger volume.

Again, if the swollen river carries the impurities to the sea it also increases the "zone of potential infection," both longitudinally down the course of the stream, and laterally by flooding low-lying lands. The subsiding flood water may also carry with it into the main stream fresh impurities.

Most of the foregoing results may be summarised for comparative purposes in one diagram as appended:—

MACCLESFIELD, ROCHDALE & STOCKPORT STORM SEWAGES.



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ADDENDUM II. TO MR. TATTON'S REPORT.

RESULTS OF THE CHEMICAL ANALYSES OF SAMPLES OF MACCLESFIELD, ROCHDALE, AND STOCKPORT SEWAGES, DILUTED WITH STORM WATER.

GEORGE McGOWAN.

Ealing,
August, 1904.

STOCKPORT STORM SEWAGE

First Series.

No. of Sample	No. 1a.	No. 1.	No. 2.	No. 3.
Nature of Sample	Crude settled sewage; "a fair sample of a bad sewage treated at the works."	Storm water, drawn when flow was 4½ times the dry-weather flow.	Storm water, drawn when flow was 4½ times the dry-weather flow.	Storm water, drawn when flow was 4½ times the dry-weather flow.
Drawn	Saturday, August 24th, 1901, 10 a.m.	Monday, August 26th, 1901, 5 p.m.	Monday, August 26th, 1901, 6 p.m.	Monday, August 26th, 1901, 7 p.m.
Analysed	August 27th, 1901.	August 27th, 1901.	August 27th, 1901.	August 27th, 1901.
Parts per 100,000 by weight.				
Ammoniacal nitrogen	2·54	2·39	0·98	0·72
Albuminoid "	0·93	0·65	0·43	0·29
Nitrous "	0·00	0·00	0·00	0·13
Nitric "	—	—	0·10	0·23
Total nitrogen by Kjeldahl method	4·86	3·38	2·17	1·58
Blank	(0·23 in 3·75)	(0·27 in 5·23)	(0·23 in 3·38)	(0·27 in 2·59)
"X" nitrogen	1·39	0·34	0·66	0·21
Total Organic nitrogen	2·32	0·99	1·09	0·50
"Oxygen absorbed" from permanganate at 26·7° C. (80°F.); *at once*	21·20	2·41	2·49	1·50
" " " " *after* 4 *hours*	*33·48	7·27	9·44	4·93
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80° F.); *at once*	—	—	7·05	4·70
Nitrous nitrogen after incubation	—	—	—	—
Incubator test (Scudder)	—	—	−	−
Incubator test, judged by smell	—	—	− (Putrid; blackened)	(Putrid; sulphides)
Chlorine	28·36	12·40	4·60	4·16
Total solids (gravimetrically)	—	—	—	—
Solids in suspension	—	—	—	—
Solids in solution	—	—	—	—
Parts per 100,000 by volume.				
Solids by centrifuge	163	187	169	137
Remarks:—	This liquid was purple-black, with a small quantity of sediment. Sewage smell, together with a peculiar sour smell; alkaline.	Very turbid greyish liquid, with considerable dark-grey sediment. Sewage smell; alkaline.	Muddy in appearance, with considerable dark brown (almost black) sediment. No smell; alkaline.	Rather turbid, slightly brown liquid, but much clearer than No. 1. The sediment was brownish. Soapy smell; alkaline.

* This figure is too low.

STOCKPORT STORM SEWAGE.

SECOND SERIES, 1903.

NO. OF SAMPLE	No. 4.	No. 5
NATURE OF SAMPLE	Sewage diluted to 3 times the dry-weather flow.	Sewage diluted to 3 times the dry-weather flow.
Drawn	Sat., Feb. 21st, 1903, 5.15 p.m.	Sat., Feb. 21st, 1903, 5.45 p.m.
Analysed	Feb. 23rd, 1903.	Feb. 23rd, 1903.
Parts per 100,000 by weight.		
Ammoniacal nitrogen	0·68	0·63
Albuminoid ,,	1·27	0·64
Nitrous ,,	0·00	—
Nitric ,,	—	—
Total nitrogen by Kjeldahl method	3·95	2·22
Blank	(0·39 in 3·08)	(0·33 in 4·29)
"X" nitrogen	2·00	0·95
Total Organic nitrogen	3·27	1·59
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	7·86	5·87
,, ,, ,, ,, ,, *after 4 hours*	40·65	18·95 (4½ hours)
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80° F.); *at once.*	9·72	—
Nitrous nitrogen after incubation	—	
Incubator test (Scudder)	—	
Incubator test, judged by smell	- (Black; putrid.)	- (Strongly putrid; black sulphides.)
Chlorine	6·50	8·08
Total solids (gravimetrically)	—	—
Solids in suspension	—	—
Solids in solution	—	—
Parts per 100,000 by volume.		
Solids by centrifuge	572	346
REMARKS:—	Brown and very turbid with a large quantity of dark brown deposit. Sewage smell. Alkaline.	Almost black-looking when the sediment was stirred up; the filtered liquid was nearly clear, and only slightly coloured. A large amount of black, gritty sediment. Distinct sewage smell. Alkaline.

MACCLESFIELD STORM SEWAGE.

First Series, 1901.

No. of Sample	No. 1.	No. 2.	No. 3.
Nature of Sample	Sewage, 3 times diluted with storm water.	Sewage, 3 times diluted with storm water.	Sewage, 3 times diluted with storm water.
Drawn	Sunday, October 6th, 1901, 12.20 noon.	Sunday, October 6th, 1901, 12.50 noon.	Sunday, October 6th, 1901, 2.30 p.m.
Analysed	October 8th, 1901.	October 8th, 1901.	October 8th, 1901.
Parts per 100,000 by weight.			
Ammoniacal nitrogen	1·20	1·31	1·73
Albuminoid ,,	0·38	0·55	0·46
Nitrous ,,	—	0·00	—
Nitric ,,	—	—	—
Total nitrogen by Kjeldahl method	2·16	2·40	2·90
Blank	(0·34 in 3·51)	(0·30 in 2·05)	(0·34 in 4·60)
"X" nitrogen	0·58	0·54	0·71
Total Organic nitrogen	0·96	1·09	1·17
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	1·23	1·49	1·22
,, ,, ,, ,, ,, *after 4 hours*	5·99	8·12	5·70
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80° F.); *at once.*	—	—	—
Nitrous nitrogen after incubation	—	—	—
Incubator test (Scudder)	—	—	—
Incubator test, judged by smell	—	—	—
Chlorine	3·38	3·70	Not noted.
Total solids (gravimetrically)	—	—	—
Solids in suspension	—	—	—
Solids in solution	—	—	—
Parts per 100,000 by volume.			
Solids by centrifuge	126	186	86
Remarks :—	Turbid and slightly brown liquid, with a large amount of dark grey-brown sediment, apparently more than in No. 6. Sewage smell, but less strong than in No. 6. Alkaline.	Turbid, with considerable black sediment. Putrid smell. Alkaline.	Turbid, with considerable amount of almost black sediment. Sewage smell. Alkaline.

MACCLESFIELD STORM SEWAGE.

SECOND SERIES, 1901.

NO. OF SAMPLE	No. 4.	No. 5.	No. 6.
NATURE OF SAMPLE	Sewage, 4 times diluted by storm water.	Sewage 3 times diluted by storm water (coloured by waste water from dye works).	Sewage 3½ times diluted by storm water.
Drawn	Tuesday, Nov. 12th, 1901, 2 p.m.	Tuesday, Nov. 12th, 1901, 2.30 p.m.	Tuesday, Nov. 12th, 1901, 3.15 p.m.
Analysed	Nov. 13th, 1901.	Nov. 13th, 1901.	Nov. 13th, 1901.
Parts per 100,000 by weight.			
Ammoniacal nitrogen	0·78	0·79	1·03
Albuminoid ,,	0·36	0·38	0·59
Nitrous ,,	Trace.	Trace.	Trace.
Nitric ,,	0.96	1·05	1·32
Total Nitrogen by Kjeldahl method	2·72	2·89	3·63
Blank	(0·30 in 2·29)	(0·33 in 4·57	(0·30 in 2·95)
"X" nitrogen	0·62	0·67	0·69
Total Organic nitrogen	0·98	1·05	1·28
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	0·79	1·50	1·61
,, ,, ,, ,, ,, *after* 4 *hours*	6·02	7·74	9·50
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80° F.); *at once.*	Lost.	·	5·06 (six days)
Nitrous nitrogen after incubation	—	—	—
Incubator test (Scudder)	—	—	—
Incubator test judged by smell	— (Putrid; blackened; sulphides).	— (Putrid; strong sulphide smell).	— (Putrid; blackened; sulphides).
Chlorine	6·12	6·84	7·20
Total Solids (gravimetrically)	61·1	..	—
Solids in suspension (by dif.)	12·7	- ·	--
Solids in solution	48·4 { 11·9 volatile 36·5 non-vol.	-	—
Parts per 100,000 by volume.			
Solids by centrifuge	98	160	150
Note by Works Manager:—"During the 24 hours preceding the taking of these samples, the sewage had been continuously diluted by storm water. For a short period in the night the dilution amounted to six times (the dry-weather flow)."	Turbid, and of a brownish tint, with considerable flocculent brown suspended matter. Clean smell. Alkaline.	Blue or blue-black turbid liquid, but not containing much (greyish-black) sediment. A kind of scent odour. Alkaline.	More turbid and of a slightly deeper tint than No. 7, and with rather more suspended matter. Doubtful smell. Alkaline.

MACCLESFIELD STORM SEWAGE.

3rd Series, 1902.

No. of Sample	No. 7.	No. 8.	No. 9.
Nature of Sample	Crude sewage, 4½ times diluted with storm water.	Crude sewage, 4 times diluted with storm water.	Crude sewage, 3½ times diluted with storm water.
Drawn	Saturday, January 4th, 1902, 2 p.m.	Saturday, January 4th, 1902, 3 p.m.	Saturday, January 4th, 1902, 4 p.m.
Analysed	January 6th, 1902	January 7th, 1902	January 6th, 1902
Parts per 100,000 by weight.			
Ammoniacal nitrogen	0·81	0·64	1·54
Albuminoid "	0·30	0·21	0·35
Nitrous "	0·00	0·12	0·13
Nitric "	0·15	0·09	0·56
Total nitrogen by Kjeldahl method	1·75	1·33	
Blank	(0·26 in 1·54)	(0·26 in 2·21)	
"X" nitrogen	0·49	0·27	—
Total Organic nitrogen	0·79	0·48	—
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	1·10	1·03	1·36
" " " " " *after 4 hours*	4·35	3·89	4·55
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80° F.); *at once.*	2·40 (seven days)	1·71 (six days)	2·39 (seven days).
Nitrous nitrogen after incubation	—	—	—
Incubator test (Scudder)		–	–
Incubator test, judged by smell	– (Putrid; sulphides)	– (Putrid; blackened)	– (Strongly putrid; sulphides.)
Chlorine	3·24	2·70	4·20
Total solids (gravimetrically)	—	—	—
Solids in suspension	—		
Solids in solution		—	—
Parts per 100,000 by volume.			
Solids by centrifuge	109	87	67
Remarks:—	Turbid and brown, with a moderate amount of flocculent sediment. Clean smell. Faintly alkaline.	Turbid, but with considerably less dark brown flocculent sediment than No. 10. Clean smell. Alkaline.	Turbid liquid, which became clear and colourless upon standing. Considerable amount of brown-grey sediment. No smell. Alkaline.

MACCLESFIELD STORM SEWAGE.

FOURTH SERIES, 1902.

NO. OF SAMPLE	No. 10.	No. 11.	No. 12.	No. 13.
NATURE OF SAMPLE	Sewage 3 times diluted, *i.e.*, 1 vol. sewage and 2 vols. rain water.	Sewage 4 times diluted, *i.e.*, 4 times the dry-weather flow.	Sewage nearly 6 times diluted, *i.e.*, 6 times the dry weather flow.	Sewage 3 times diluted, *i.e.*, 3 times the dry-weather flow.
Drawn	Tues., July 1st, 1902, 2.45 p.m.	Tues., July 1st, 1902, 3 p.m.	Tues., July 1st., 1902, 3.15 p.m.	Tues., July 1st, 1902, 4 p.m.
Analysed	July 2nd, 1902.	July 2nd, 1902.	July 2nd, 1902.	July 2nd, 1902.
Parts per 100,000 by weight.				
Ammoniacal nitrogen	4·08 } 5 drops Na_2CO_3Aq. added	5·19	3·41 } 5 drops Na_2CO_3Aq. added.	1·55
Albuminoid ,,	1·11	3·21	4·07	0·91
Nitrous ,,	—	—	—	
Nitric ,,	—	—	—	-
Total nitrogen by Kjeldahl method	6·34	14·39	11·64	3·48
Blank	(0·33 in 4·94	(0·41 in 11·94)	(0·33 in 8·79)	(0·41 in 3·20)
"X" nitrogen	1·15	5·99	4·16	1·02
Total organic nitrogen	2·26	9·20	8·23	1·93
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	4·67	12·95	10·83	3·30
,, ,, ,, *after 4 hours*	15·70	36·90	37·24	9·75
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80 F.); *at once.*		·	--	
Nitrous nitrogen after incubation	-	—	—	
Incubator test (Scudder)	—	—	--	—
Incubator test, judged by smell	—	—	—	·
Chlorine	10·90	11·88	7·56	4·26
Total solids (gravimetrically)	121·9 { 57·9 vol. 64.0 non-vol.	336·2 { 143·4 vol. 192·8 non-vol.	310·3 { 132·0 vol. 178·3 non-vol.	79·1 { 31·5 vol. 47·6 non-vol.
Solids in suspension	58·1 { 45·9 vol. 12·2 non-vol.	246·3 { 105·4 vol. 140·9 non-vol.	†258·8 { 117·9 vol. 140·9 non-vol	32·7 { 14·8 vol. 17·9 non-vol.
Solids in solution	* 63·8 { 12·0 vol. 51·8 non-vol.	89·9 { 38·0 vol. 51·9 non-vol.	† 51·5 { 14·1 vol. 37·4 non-vol.	46·4 { 16·7 vol. 29·7 non-vol.
Parts per 100,000 by volume.				
Solids by centrifuge	254	Too coarse.	Too coarse.	212
REMARKS :—	Milky, with a large quantity of brown sediment; opalescent when filtered. Faint sewage smell. Alkaline.	Very foul liquid, containing a very large amount of course black sediment, which rendered sampling difficult. Sewage smell. Alkaline.	Very turbid, with a very large amount of coarse black sediment. Strong sewage smell. Alkaline.	Not so foul as No. 14, though with a sewage smell. A large amount of black sediment, though again not nearly so much as in No. 14.

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* Done on July 9th. † Done on July 9th; therefore approximate.

MACCLESFIELD STORM SEWAGE.

Fifth and Sixth Series, 1902–3.

No. of Sample	No. 14.	No. 15.	No. 16.	No. 17
Nature of Sample	Sewage diluted 5 times.	Sewage diluted 4 times.	Sewage diluted 3 times.	Sewage diluted to 4½ times the dry-weather flow; for 9 hours previously the sewage had been diluted to 3 times the normal; heavy rains on the 5th and 6th had flushed out the sewers.
Drawn	Thursday, July 10th, 1902, 12 noon.	Thursday, July 10th, 1902, 1.15 p.m.	Thursday, July 10th, 1902, 2.30 p.m.	Wednesday, January 7th, 1903, 3·30 p.m.
Analysed	July 12th, 1902.	July 12th, 1902.	July 12th, 1902.	January 8th, 1903.
Parts per 100,000 by weight.				
Ammoniacal nitrogen	—	—	—	0·48
Albuminoid "	—	—	—	0·34
Nitrous "	—	—	—	0·00
Nitric "	—	—	—	0·0
Total nitrogen by Kjeldahl method	1	1·56	1·70	1·57
Blank	0·41 in 2·50)	(0·41 in 1·66)	(0·41 in 1·77)	(0·33 in 2·57)
"X" nitrogen	—	—	—	0·75
Total Organic nitrogen	—	—	—	1·23
"Oxygen absorbed" from permanganate at 26·7° C. (80 F.); *at once*	1	1·42	0·99	1·51
" " " *after 4 hours*	·44	4·78	4·2	6·03
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80° F.); *at once.*		—	—	—
Nitrous nitrogen after incubation	—	—	—	—
Incubator test (Scudder)	—	—	—	—
Incubator test, judged by smell	Very putrid; sulphides.	Putrid; sulphides.	Putrid; sulphides.	—
Chlorine	—	—	—	2·20
Total solids (gravimetrically)	152·8 {35·0 vol. 117·8 non-vol.	57·9 {16·6 vol. 41·3 non-vol.	55·3 {13·6 vol. 41·7 non-vol.	—
Solids in suspension	141·0 {31·6 vol. 109·4 non vol.	41·4 {13·4 vol. 28·0 non-vol.	31·1 {7·2 vol. 23·9 non-vol.	--
Solids in solution	11·8 {3·4 vol. 8·4 non-vol.	16·5 {3·2 vol. 13·3 non-vol.	24·2 {6·4 vol. 17·8 non-vol.	
Parts per 100,000 by volume.				
Solids by centrifuge	Too coarse.	Too coarse.	Too coarse.	126
Remarks:—	Turbid, greyish-yellow liquid, with a large amount of blackish-brown gritty sediment. Soapy smell; alkaline.	Clearer and less coloured than No. 17, and with considerably less sediment (which was rather flocculent). Soapy smell; alkaline.	Turbid, yellowish liquid like No. 17, but with less sediment, which was partly flocculent and partly gritty. Soapy smell; alkaline.	Brown turbid liquid, but quite clear when filtered; a considerable amount of dark flocculent and gritty sediment. No smell; alkaline.

ROCHDALE STORM SEWAGE.

FIRST SERIES, 1902.

NO. OF SAMPLE	No. 1.	No. 2.	No. 3
NATURE OF SAMPLE	Sewage, 3 times diluted by storm water, *i.e.*, 1 vol. of sewage and 2 vols. of rain water.	Sewage, 5 times diluted by storm water.	Sewage, 7 times diluted by storm water.
Drawn	Friday, April 4th, 1902, 5.30 p.m.	Saturday, April 5th, 1902, 3.15 p.m.	Saturday, April 5th, 1902, 4.15 p.m.
Analysed	April 5th, 1902.	April 7th, 1902.	April 7th, 1902.
Parts per 100,000 by weight.			
Ammoniacal nitrogen	1·24	0·85	1·22
Albuminoid ,,	0·55	0·59	0·63
Nitrous ,,	0·00	0·02	0·00
Nitric ,,	0·32	0·13	0·03
Total nitrogen by Kjeldahl method	2·92	2·23	2·66
Blank	(0·38 in 2·72)	(0·35 in 1·98)	(0·35 in 2·29)
"X" nitrogen	0·81	0·64	0·78
Total Organic nitrogen	1·36	1·23	1·41
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	3·15	4·11	4·99
,, ,, ,, ,, ,, *after* 4 *hours*	11·39	10·33	13·49
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7° C. (80° F.) *at once.*	—	—	—
Nitrous nitrogen after incubation	—	—	—
Incubator test (Scudder)	—	—	—
Incubator test, judged by smell	Very strongly putrid.	Blackened; putrid; sulphides.	Blackened; putrid; sulphides.
Chlorine	7·30	3·72	—
Total solids (gravimetrically)	88·2 {39·5 vol. 48·7 non-vol.	40·6 {15·0 vol. 25·6 non-vol.	50·4 {8·9 vol. 31·5 non-vol.
Solids in suspension	30·3 {17·9 vol. 12·4 non-vol.	23·2 {9·5 vol. 13·7 non-vol.	33·7 {13·5 vol. 20·2 non-vol.
Solids in solution	57·9 {21·6 vol. 36·3 non-vol.	17·4 {5·5 vol. 11·9 non-vol.	16·7 {5·4 vol. 11·3 non-vol.
Parts per 100,000 by volume.			
Solids by centrifuge	94	480	467
REMARKS:—	Greyish brown turbid liquid, with a smell of soap-suds. Not very much sediment, which was blackish. Alkaline.	Very turbid and dark brown in colour, with a large amount of black sediment; very slight tarry smell.	Very turbid and dark brown, with apparently rather more black sediment than No. 2. Very slight tarry smell. Alkaline.

ROCHDALE STORM SEWAGE.

SECOND SERIES, 1902.

No. of Sample	No. 4.	No. 5.	No. 6.	No. 7.
Nature of Sample	Sewage diluted to 6 times the dry-weather flow.	Sewage diluted to 5 times the dry-weather flow.	Sewage diluted to 4 times the dry-weather flow.	Sewage diluted to 3 times the dry-weather flow.
Drawn	Friday, May 2nd, 1902, 1.40 p.m.	Friday, May 2nd, 1902, 2.5 p.m.	Friday, May 2nd, 1902, 2.30 p.m.	Friday, May 2nd, 1902, 3 p.m.
Analysed	May 5th, 1902.	May 5th, 1902.	May 5th, 1902.	May 5th, 1902.
Parts per 100,000 by weight.				
Ammoniacal nitrogen	1·62	1·33	1·40	1·24
Albuminoid ,,	1·23	1·07	1·26	0·49
Nitrous ,,	0·00	0·00	0·00	0·00
Nitric ,,	—	0·00	0·00	0·08
Total nitrogen by Kjeldahl method.	6·61	3·73	4·09	2·54
Blank	(0·38 in 10·97)	(0·35 in 5·77)	(0·35 in 6.30)	(0·38 in 4·45)
"X" nitrogen	3·76	1·33	1·43	0·73
Total Organic nitrogen	4·99	2·40	2·69	1·22
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	21·51	4·71	6·32	4·76
,, ,, ,, ,, ,, *after 4 hours*	44·99	19·70	21·09	11·02
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7°C. (80°F.); *at once.*	—	—	—	—
Nitrous nitrogen after incubation	—	—	—	—
Incubator test (Scudder)	—	—	—	—
Incubator test judged by smell	Putrid, but not very bad; blackened. (May 24th.)	Very putrid; blackened; strong sulphide smell.	Blackened and very putrid; sulphides.	Blackened; putrid; sulphides. (May 24th.)
Chlorine	4·22	4·74	4·94	(*a*) 7·08, (*b*) 7·00.
Total solids (gravimetrically)	401·2 {121·4 vol. 279·8 non-vol.	161·3 {56·8 vol. 104·5 non-vol.	198·3 {89·0 vol. 109·3 non-vol.	88·4 {28·8 vol. 59·6 non-vol.
Solids in suspension	366·4 {112·2 vol. 254·2 non-vol.	124·0 {47·2 vol. 76·8 non-vol.	145·1 {69·4 vol. 75·7 non-vol.	40·4 {7·0 vol. 33·4 non-vol.
Solids in solution	34·8 {9·2 vol. 25·6 non-vol.	37·3 {9·6 vol. 27·7 non-vol.	53·2 {19·6 vol. 33·6 non-vol.	48·0 {21·0 vol. 26·2 non-vol.
Parts per 100,000 by volume.				
Solids by centrifuge	Not done.	465	464	Not done.
Remarks :—	Very dark, almost black, turbid liquid. The liquid itself was brown when the sediment had settled. Very large amount of sediment, which evidently consisted in part of ferrous iron, as it turned brown on standing. Tarry smell. Alkaline.	Very turbid and black, but the filtered liquid almost colourless. Much coarse black sediment. Slight sewage smell. Alkaline.	Very turbid and whitish in appearance, from what was apparently precipitated sulphur. Very considerable black sediment, not so coarse as in No. 5. Slightly sour smell. Alkaline.	Greenish and turbid soapy-looking liquid, with a considerable amount of dark-coloured sediment. Soapy smell. Alkaline.

ROCHDALE STORM SEWAGE.

THIRD AND FOURTH SERIES.—1902-3.

No. of Sample	No. 8.	No. 9.	No. 10.	No. 11.
Nature of Sample	Sewage diluted to 3 times the dry-weather flow.	Sewage diluted to 3 times the dry-weather flow.	Sewage diluted to 5 times the dry-weather flow.	Sewage diluted to 3 times the dry-weather flow.
Drawn	Friday, October 10th, 1902, 1 p.m.	Monday, January 5th, 1903, 12 noon.	Monday, January 5th, 1903, 2 p.m.	Monday, January 5th, 1903, 3.10 p.m.
Analysed	October 13th, 1902.	January 6th, 1903.	January 6th, 1903.	January 6th, 1903.
Parts per 100,000 by weight.				
Ammoniacal nitrogen	—	1·48	0·76	0·42
Albuminoid ,,	—	0·65	0·57	0·40
Nitrous ,,	—	Doubtful trace.	0·00	Trace.
Nitric ,,	—	—	0.00	Trace.
Total nitrogen by Kjeldahl method.	5·19	2·85	2·18	2·01
Blank	(0·40 in 4·10)	(0·32 in 2·26)	(0·33 in 3·44)	(0·32 in 1·69)
"X" nitrogen	—	0·72	0·84	1·19
Total Organic nitrogen	—	1·37	1·41	1·59
"Oxygen absorbed" from permanganate at 26·7° C. (80° F.); *at once.*	5·52	3·15	4·12	2·03
,, ,, ,, *after 4 hours*	14·52	14·42	12·06	11·40
"Oxygen absorbed" from permanganate by sample incubated for 5 days at 26·7°C. (80°F.); *at once.*	—	—	—	—
Nitrous nitrogen after incubation	—	—	—	—
Incubator test (Scudder)	—	—	—	—
Incubator test, judged by smell	—	Very putrid and blackened.	—	Very putrid and blackened.
Chlorine	7.80	4·10	2·60	1·68
Total solids (gravimetrically)	126·9 {52·6 vol. 74·3 non-vol.	78·6 {30·8 vol. 47·8 non-vol.	125·8 {79·0 vol. 46·8 non-vol.	—
Solids in suspension	78·4 {35·3 vol. 43·1 non-vol.	50·8 {22·4 vol. 28·4 non-vol.	108·1 {75·8 vol. 32·3 non-vol.	—
Solids in solution	48·5 {17·3 vol. 31·2 non-vol.	27·8 {8·4 vol. 19·4 non-vol.	17·7 {3·2 vol. 14·5 non-vol.	—
Parts per 100,000 by volume.				
Solids by centrifuge	338	*258	Solids too coarse for the centrifuge tube.	†204
REMARKS:—	Greyish-black turbid liquid, with a considerable amount of grey-black flocculent sediment. The filtered liquid was almost clear and colourless. Putrid smell. Alkaline on boiling.	Very black, with considerably more black sediment than No. 11. Soapy smell. Alkaline. Grit up to 0·3 m.m. long; aggregated solids and fibre too large to measure (microscopically)	Very turbid brown liquid, but clear when filtered. A large amount of coarse, black, gritty and flocculent sediment. Distinct odour of tar. Alkaline.	Very black, with much fibrous black sediment. Soapy smell. Alkaline. There were very large fragments (microscopically) of solids and of fibre; the grit was not quite so large as in No. 9.

---

* The very large solids were rejected.

† The large solids were again rejected.

NOTES BY DR. McGOWAN ON THE FOREGOING ANALYSES.

It will be seen from Mr. Tatton's Report that nearly all the samples examined have been drawn on the ascending curve of the storm, the dilutions ranging between three and seven times the dry weather flow, in the majority of cases three to four times. In quality these storm sewages might be classed as varying between exceptionally strong and very weak sewages, nearly half of them being weak, and the remainder medium to strong. A few of them contained extraordinary amounts of suspended solids (up to 366 parts per 100,000), others only small quantities. When the samples came to be analysed, about two-thirds of them were more or less inoffensive as regards smell, the remaining third having a sewage odour. Fully half of them were subjected to the incubator test, with the result that they became putrid; and no doubt all the others would have done the same. In comparing sets of samples drawn on the same day, at intervals during the storm, it was seen that the liquid might continue to be bad during a flow of two or three hours—a point of great importance.

The results are sufficient to emphasize the necessity for settling and treating storm waters up to the limit of dilution that a sewerage system may reasonably be asked to provide for.

It will be observed that all the samples were examined *as a whole*, *i.e.*, without a preliminary filtration through paper. Looking back on the results, it would have been well if some, at least, of these storm waters had been settled or, perhaps, filtered through paper before being analysed, with the object of seeing how much of the impurity present was due to suspended solids alone. Samples No. 2 (Stockport), and Nos. 4 7, 8, 9 and 17 (Macclesfield), had a clean smell on the day of analysis, and quite possibly some of the others may have been inoffensive as regards smell at the time they were drawn.

G. M.

Ealing, August, 1904

ROYAL COMMISSION ON SEWAGE DISPOSAL.

SUPPLEMENTARY VOLUMES PRESENTED WITH THE

FIFTH REPORT

OF

THE COMMISSIONERS

APPOINTED TO INQUIRE AND REPORT WHAT METHODS OF

Treating and Disposing of Sewage

(INCLUDING ANY LIQUID FROM ANY FACTORY OR MANUFACTURING PROCESS)

MAY PROPERLY BE ADOPTED.

APPENDIX VI.

REPORT

BY PROFESSOR LETTS AND DR. W. E. ADENEY, ON THE

POLLUTION OF ESTUARIES AND TIDAL WATERS.

Presented to both Houses of Parliament by Command of His Majesty.

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STANDARDS FOR TIDAL WATERS.

Introduction and General Scope of Report.

In presenting this Report we desire to make the following observations :—

When we were requested to draw up a Report on the question of Standards for Tidal Waters in relation to Offensive Putrefaction and Injury to Fish, we did not anticipate any serious difficulties in the matter, nor did we think that any considerable period of time would be required for the work.

Much had apparently been done on the subject both in this country and abroad, and the mere collection and collation of the known data was, relatively speaking, a simple matter.

We soon found, however, that if our Report was to have any real or lasting value, a great deal more was necessary than a carefully prepared review of the then known facts ; for when these were collected and arranged they were found to leave us scarcely beyond the margin of the subject, and face to face with a number of questions which demanded investigation.

The nature and rate of the chemical changes occurring in river and sea water, when polluted by sewage or by trade wastes, with the attendant loss in dissolved oxygen ; the allowable limits of pollution with safety to fish life ; the rate at which river and sea water can take up fresh oxygen from the air and become re-aerated after de-aeration by pollution ; the nature and causes of the chemical changes by which nuisances originate either directly from sewage pollution of the waters or the bed of a tidal locality, or indirectly from sewage pollution of the water by the growth and subsequent decay of green seaweeds, are among the more important of these.

We have, as a consequence, found it necessary to exceed our instructions, and to submit certain of these questions, as well as some others, to experimental inquiry. This has required a considerable expenditure of time, and therefore the presentation of our Report has been delayed.

In order to ascertain, as far as possible, what was being done by towns situated either on tidal rivers, estuaries, or on the coast, as regards the disposal of their sewage, and the experience which they had gained, we addressed a number of questions on the subject to the Medical Officers of Health of numerous towns in the United Kingdom, with the kind assistance of the Secretary of the Commission, Mr. F. J. Willis. Their replies have furnished some valuable information, which will be found recorded in an Appendix to this Report.

At an early stage of our inquiries we found it advisable to inspect a certain number of Estuaries in England, which might be regarded as typical of the three different classes into which tidal waters, we think, should be grouped according to the natural facilities which they present for the transport or disposal of sewage matters, and to investigate the effects of sewage pollution upon the aeration of their waters, and upon the growth of certain green seaweeds. This we did in the summer of 1904, and the result of our observations will be found in the Section on "Selected Localities where the Tidal Waters are Polluted."

In the same section we also describe more detailed and thorough examinations than were possible in these cases of the waters of two tidal localities in Ireland, namely, Belfast and Dublin, which, owing to circumstances which need not be specified here, we had been respectively called upon to investigate as completely as possible—one of us as regards the Liffey from Dublin to the mouth of the estuary, and the other in relation to the treatment of the sewage of Belfast and its effects on the Lough.

We regret that with the time at our disposal it was not possible to examine any tidal localities in Scotland, and especially Glasgow and the estuary of the Clyde.

While we have endeavoured to make our Report as complete as possible, it is scarcely necessary to say that there are many points connected with the pollution of tidal waters which still require investigation. The whole subject has, in fact, received comparatively little accurate study until recently, but its importance is becoming more and more apparent.

* * * * * *

While in some respects the pollution of tidal waters involves the same disadvantages and dangers as that of non-tidal waters, and while these may be traced to similar chemical or physical causes, there are certain very distinct points of difference between the two classes of pollution to which attention may be drawn.

In the first place the pollution of an estuary does not involve the question of pathogenic organisms in relation to a water supply used for drinking or other domestic purposes.

Secondly, there are the effects of tidal action, which twice in the 24 hours causes an outward flow of the polluting matters, either into, or at least towards the open sea, where the dilution may be so great that for all practical purposes these substances are dissipated, the estuary bed being well scoured during the period of ebb, and parts of its surface freely exposed to the purifying effects of the air, these actions being followed later by corresponding inflows of more or less pure sea water, the estuary being thus submitted by nature to the alternate effects of scour and flush.

The extent, however, to which the polluting matters will be driven out to sea, or so diluted as to become innocuous, must obviously depend upon a variety of circumstances, among which the most important are the configuration, and more particularly the length of the estuary, the height of the tidal wave, the volume of the sewage, and the amount of land water passing downwards—this last in the case of a long and narrow channel being no doubt the chief determining factor in the transport of the sewage towards the sea.

If, in such a case, the flow of land water is relatively small, the sewage may be driven seawards only very slowly, the main quantity, supposing it to be discharged on the ebb tide, being carried down the estuary a certain distance only, and then driven back again by the flood until it approaches the outfall, from which another charge of sewage is added as the tide falls again. Thus, a certain region may exist where the estuary is always extensively polluted with sewage owing to tidal oscillations, a "Sewage Zone" as it has been termed, which in addition to other harmful effects may act as an effectual barrier to the upward or downward passage of migratory fish.

This zone will be driven higher up the estuary as the tidal range increases from neaps to springs, and may be carried to a considerable distance above the outfall.

Another point which must not be lost sight of in contrasting the effects which may be produced by mixtures of sewage with fresh water and with sea water respectively, but which appears to have escaped general attention, is that the two media, *i.e.*, fresh water and sea water, dissolve very different quantities of oxygen when fully aerated at the same temperature, sea water containing nearly 20 per cent. less than fresh water.

But, on the other hand, it has been found as a result of one of the investigations that have been specially made for this Report, that sea water becomes re-aerated after de-aeration by pollution, nearly three times more quickly than river water under like conditions.

The discharge of crude sewage into the open sea, so extensively resorted to as the means of disposal in many of the chief watering places situated on our coasts, involves somewhat different considerations from those attending the pollution of estuaries.

In such cases, and with a properly situated outfall, the extent of dilution is often so large as to preclude all possibility of a nuisance occurring, and the tidal currents are as a rule sufficiently strong to remove and dissipate the polluting matters without fear of their return, or of their deposition in dangerous proximity to the shore.

But while the discharge both of crude sewage and trade effluents into estuaries or the open sea may in many cases be both economical and safe, in others it leads to evils of various kinds, some of which are apparent and direct, while others are more obscure and of an indirect nature.

If the estuary is small and the volume of sewage large, a nuisance may arise of the same nature, and mainly from the same causes as that of an inland stream. In other cases, where the estuary is relatively large, but the tides sluggish, a nuisance may be indirectly caused by the growth and subsequent decay of masses of green seaweeds.

Deposits of sewage matters may be formed, which actually interfere with navigation and which have to be dredged away at considerable expense; or these deposits may remain at the margins of the estuary, where they are not only unsightly and evil-smelling, but also dangerous to public health. And again, in certain cases sludge deposits may be formed in the neighbourhood of submerged outfalls, the presence of which is not even indicated in calm weather, but which are disturbed and washed onto the shore during gales.

The pollution of an estuary may lead to harmful results of a different character. Fish, such as the migratory *salmonidæ*, may either be hindered or actually prevented from ascending or descending the rivers; while it has been stated that even sea fish may be driven away and their spawning beds destroyed.

The effects of sewage pollution on many estuaries are only too apparent, and it is significant that certain large cities situated on tidal streams, such as Glasgow, Belfast and Dublin, have voluntarily undertaken schemes of sewage purification.

In this Report an attempt is made to approach the question of the discharge of sewage into tidal waters from both the theoretical and practical standpoints. On the one hand the differences between fresh and sea water in relation to de-aeration and to re-aeration, as well as the nature of the chemical changes which occur in mixtures of the two with sewage or other polluting matters, are inquired into, and the natural agencies inducing the self-purification of such mixtures are discussed. While, on the other hand, the actual effects caused by the pollution of tidal waters are examined with special reference to the reduction of nuisances arising either directly or indirectly from such pollution, the deposition of solids in navigable channels, and the effects of pollution on fish life.

The chief localities where the pollution of tidal waters has led to harmful results in these different directions are enumerated as far as possible, and the conditions obtaining in each are described and reviewed.

Finally the conclusions to be drawn from the inquiries into these different questions are considered with special reference to the possibility of framing practical standards which shall set a limit to the extent of pollution which may be permitted in a given estuary or tidal water.

In order to avoid undue delay in presenting our Report we early found it necessary to divide the work as far as possible between us, each taking up those portions with which his own investigations had made him more particularly conversant. Our Report is accordingly presented in a number of different sections.

W. E. Adeney.
E. A. Letts.

November, 1907.

SECTION 1.

THE CHEMICAL CHANGES WHICH OCCUR IN POLLUTED FRESH AND SALT WATERS

AND

THE RATE OF AERATION OF FRESH AND SALT WATERS.

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CHEMICAL CHANGES WHICH OCCUR IN POLLUTED FRESH AND SALT WATERS.

INTRODUCTION.

It is the object of this section to explain the nature of the chemical changes, so far as they have been investigated, which sewage matters of various kinds undergo, when they are discharged into tidal waters.

The most important effect upon tidal waters of the introduction of sewage into them, and one which invariably follows it, is the more or less complete absorption of their dissolved oxygen.

The loss of oxygen may be brought about in three different ways: (1) The sewage waters from their own state of de-aeration may lower the aeration of the unpolluted water by dilution. (2) They may contain directly and easily oxidisable substances, which on becoming mixed with unpolluted water will cause a more or less rapid loss of its dissolved oxygen. (3) The organic constituents of the sewage, which are not directly oxidisable (and they usually form the greater part of it), and ammonium compounds, are oxidised through the agency of water bacteria, and thus indirectly cause a loss of dissolved oxygen.

These possible causes of de-aeration are enumerated in the order in which they would in all probability take effect under natural conditions. The first is obvious, although its importance has not perhaps been sufficiently recognised. Its effects can easily be differentiated from those of the other two. The second will also be readily admitted as self-evident, and in some cases, its effects can be distinguished without difficulty from those of the others, but not always. The third will require careful discussion, and we shall consider it in detail, pointing out when in some cases its effects can be differentiated from those of the second phase of de-aeration, and when they cannot.

As regards the bacteriology of the living organisms, it is not within the province of this Report to deal with it. It will therefore be assumed that the chemical changes which accompany indirect oxidation are the result of vital processes of living water organisms when growing and multiplying in the polluted water.

From the chemical point of view, a polluted water is to be regarded on this assumption as a liquid undergoing bacterial fermentation, during which, and until the original polluting matters are completely changed, oxygen will be absorbed, and certain products formed, which may or may not be offensive and dangerous to public health and to fish, according to whether a continual excess of dissolved oxygen remains throughout the liquid or not.

As regards offensive products of fermentation, ample evidence will be found from the investigations which we shall summarise, to show that they do not appear amongst products of fermentation provided that continual aerobic conditions be established in the water. It is consequently unnecessary to consider them in detail, except the conditions necessary for the avoidance of their formation.

This branch of our inquiry will, therefore, be confined to the consideration of:—

(1) The course and nature of the chemical changes which occur during aerobic fermentation of sewage matters in waters.

(2) The relationship of the oxygen absorbed to the sewage matters originally present, and to the products formed.

(3) The rate of re-aeration of waters under natural conditions, which have been de-aerated by pollution.

(4) The maximum rate at which dissolved oxygen in waters, exposed to natural conditions, may be absorbed by polluting matters within the limits of aerobic conditions.

(5) The formulation of standards of impurity for sewage and for sewage effluents.

PART I.

THE COURSE AND NATURE OF FERMENTATIVE CHANGES IN POLLUTED WATERS UNDER CONTINUAL AEROBIC CONDITIONS.

The late Sir E. Frankland, K.C.B., studied the changes which occur in polluted waters, so far as they could be by purely chemical methods, in the classic investigations which he carried out for the Rivers Pollution Commission, and he amply proved that the course of change was essentially one of oxidation. We quote the following table from the First Report of the Rivers Pollution Commission, p. 63, as illustrative of the changes which London sewage undergoes during the process of purification on passage through a sufficient thickness of sand :—

TABLE 1.—Downward filtration of London sewage through fifteen feet of sand. Results of Analysis expressed in parts per 100,000. (Frankland.)

Description.	Total solid Matters in solution.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates and Nitrites.	Total combined Nitrogen.
Average composition of sewage before filtration* - - -	64·5	4·386	2·484	5·557	·000	7·060
Filtration at rate of 2·8 gallons per cubic yard per 24 hours.						
Effluent water, Dec. 21st, 1868	82·8	·993	·187	·030	3·227	3·439
„ „ „ 28th, „	88·1	·849	·166	·022	4·468	4·652
„ „ Jan. 4th, 1869	85·2	·893	·140	·013	4·489	4·639
„ „ „ 11th, „	91·1	1·013	110	·020	4·830	4·956
„ „ „ 18th, „	77·0	·854	·179	·020	4·554	4·749
At rate of 4·2 gallons per cubic yard per 24 hours.						
Effluent water, Jan. 25th, 1869	60·2	·936	·140	·012	2·265	2·415
„ „ Feb. 1st, „	86·3	·766	·078	·025	5·105	5·204
„ „ „ 8th, „	94·2	·892	·102	·020	5·155	5·273
„ „ „ 15th, „	80·6	1·311	·089	·015	4·156	4·257
At rate of 5·6 gallons per cubic yard per 24 hours.						
Effluent water, Feb. 22nd, 1869	69·9	·827	·110	·015	3·617	3·739
„ „ Mar. 1st. „	86·8	·711	·078	·010	4·727	4·813
„ „ „ 8th, „	79·1	·664	·136	·012	3·431	3·577
At rate of 11·2 gallons per cubic yard per 24 hours.						
Effluent water, Mar. 15th, 1869	70·0	1·261	·522	1·680	2·841	4·746
„ „ „ 22nd, „	56·4	·537	·107	·064	2·484	2·644
„ „ „ 30th, „	76·0	2·007	2·096	4·790	·035	6·076
„ „ April 5th, „	70·7	1·948	1·041	3·195	·812	4·484

---

* These figures give the average results of 21 analyses of the sewage used during the continuance of these and the following experiments. It need scarcely be stated that in reality the composition of the sewage varied considerably during the course of the experiments. The variation may often be traced in the total solid matters and total combined nitrogen in the effluent water. It was obviously impossible to make the analyses of the sewage contemporaneously with those of the effluent water so as to admit of a strict comparison between the two. The following numbers show the maximum and minimum results obtained in the 21 analyses of sewage just referred to. The whole series of these analyses is recited on p. 35, where it will be seen that the low minimum of ·909 of organic nitrogen occurred on only one occasion, and that the next lowest number was 1·378 :—

——	Total Solid Matters in solution.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates and Nitrites.	Total combined Nitrogen.	Chlorine.
Maximum -	80·1	6·345	4·977	9·325	·012	11·187	15·1
Minimum -	40·6	2·596	·909	2·445	·000	2·923	5·1

The oxidation of organic and ammoniacal nitrogen to nitrates and nitrites which is indicated by these experiments affords ample evidence of the oxidising nature of the purifying process to which the sewage matters were submitted. But the experiments show with equal clearness that the process was an exceptional one. Thus, although the ammonia was practically all oxidised, quite a considerable fraction of the organic carbon and nitrogen escaped complete oxidation, and remained in the form of organic matter after passage through the filtering material. This is the more surprising when the fact, now well known, is remembered that the organic matters which survive efficient filtration of sewage are rapidly oxidised by chemical agents, such as acid potassium permanganate.[†]

It will also be observed on reference to the table that the total combined nitrogen in the effluent was not in a single experiment equivalent to the organic and ammoniacal nitrogen originally present in the sewage.

It is impossible to avoid the conclusion, therefore, that the process of oxidation which is set up in sewage matters during purification on passage through the material of a filter is a selective one, and in many respects exceptional when compared with the oxidising processes which are set up by the direct chemical action of ordinary oxidising agents.

We may finally note in reference to these experiments that, under the conditions of the experimental filter which Frankland employed, the rate of change in the sewage matters was extremely rapid, being complete within twenty-four hours when the filter was not overdosed by a too rapid flow of the sewage.

We now know that the rapid purification which is effected by a bacterially active percolating filter is largely due to the very large numbers of organisms which accumulate on the surfaces of the material of the filter, and to the ample supply of oxygen on the one hand, and to the intimate manner in which both are brought in contact with the polluted water on the other hand, as the latter passes in thin films through the filter.

Frankland was not so fortunate in the results which he obtained from his consideration of the question of the "self-purification" of polluted rivers. We cannot do better than quote his own words on this subject.

[*] "We have made this experiment by mixing the Grand Junction Company's Thames water with 5 per cent. of fresh London sewage. The organic carbon, organic nitrogen, and dissolved oxygen were immediately determined in one portion of the mixture, and the remainder was then enclosed in a series of well stoppered bottles, which were exposed to diffused daylight and kept at a temperature of about 17°C. One of these was opened every twenty-four hours, except on an intervening Sunday, and the weight of dissolved oxygen contained in the enclosed water determined by boiling off the dissolved gases *in vacuo*. The following results were obtained :—

"Rate of Oxidation of Sewage in Water.

Weight of dissolved Oxygen in 100,000 parts of the Water.						
Immediately after mixture.	After 24 hours.	After 48 hours.	After 96 hours.	After 120 hours.	After 144 hours.	After 168 hours.
·946	·803	·616	·315	·201	·080	·036

"Immediately after mixture the sewage contaminated water contained in 100,000 parts 2·099 part organic carbon and ·207 part organic nitrogen.

"These numbers show that even in warm weather the oxidation of the animal organic matter in sewage takes place very slowly. Leaving altogether out of the question the oxidation of the hydrogen and nitrogen, and assuming that for the destruction of the organic matter the carbon alone requires to be oxidised (3 parts by weight of carbon requiring for this purpose 8 parts of oxygen), then the percentage of sewage destroyed in each of the above periods will be as follows :—

——	Percentage of Sewage destroyed.
1st period of 24 hours - - - -	6·8
2nd „ 24 „ - - - - -	8·9
3rd „ 48 „ - - - - -	14·3
4th „ 24 „ - - - - -	5·4
5th „ 24 „ - - - - -	5·8
6th „ 24 „ - - - - -	2·1
	43·3

---

[*] First Report Rivers Pollution Commission, p. 50.

[†] See p. 55.

"Up to the end of the sixth day (or fifth period) the oxidation took place at a tolerably constant, though somewhat diminishing, rate; the amount of oxygen still left in solution, however, had then become so small as greatly to retard the rate during the next twenty-four hours when the experiment was discontinued. Assuming, however, that if the polluted water had been constantly exposed to the air, a portion at least of the oxygen would have been replaced, and assuming, further, that the oxidation proceeded during 168 hours at the maximum rate observed, then at the end of that time only 62·3 per cent. of the sewage would have been oxidised.

"It is thus evident that, so far from sewage mixed with twenty times its volume of water being oxidised during a flow of ten or twelve miles, scarcely two-thirds of it would be so destroyed in a flow of 168 miles at the rate of one mile per hour, or after the lapse of a week. But even this result is arrived at by a series of assumptions which are greatly in favour of the efficiency of the oxidising process. Thus, for instance, it is assumed that the 62·3 per cent. of sewage is thoroughly oxidised and converted into inoffensive organic matter; but the experiments showed that, in fact, no sewage whatever was so converted or destroyed even after the lapse of a week, since the amount of carbonic acid dissolved in the water remained constant during the whole period of the experiment, whilst, if the sewage had been converted into inorganic compounds, the carbonic acid, as one of these compounds, must have increased in quantity.

"Thus whether we examine the organic pollution of a river at different points of its flow, or the rate of disappearance of the organic matter of sewage when the latter is mixed with fresh water and violently agitated in contact with air, or, finally, the rate at which dissolved oxygen disappears in water polluted with 5 per cent of sewage, we are led in each case to the inevitable conclusion that the oxidation of the organic matter in sewage proceeds with extreme slowness, even when the sewage is mixed with a large volume of unpolluted water, and that it is impossible to say how far such water must flow before the sewage matter becomes thoroughly oxidised. It will be safe to infer, however, from the above results that there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation."

It will be noted that in the foregoing experiment Frankland failed to detect the formation of carbon dioxide coincidently with the absorption of oxygen. He states "the amount of carbonic acid dissolved in the water remained constant during the whole period of the experiment." We now know that this gas was in all probability formed, but that he failed to detect it owing, no doubt, to the practical impossibility of completely disengaging it, when it occurs in the free state in the water together with bicarbonates, by boiling the water *in vacuo*, unless the condition for the disengagement of the whole of the gas, both free and combined, be established by the previous addition of a little sulphuric acid to the apparatus in which the extraction *in vacuo* is effected.

As regards the conclusion which Frankland arrived at in reference to the self-purification of polluted rivers, it must be remembered that the interpretation which he placed upon his results was made under the impression that the chemical changes which he was studying were the result of direct chemical oxidation.

We now know that this was not so, but that the changes were brought about by the physiological processes of living organisms, and that these latter may vary in numbers and activity, under different conditions, to such an extent as to completely upset the calculations and conclusions which he made from his experiments.

Not only is the course of oxidation set up in a polluted water exceptional, as already indicated, but it is much more energetic and complete than that brought about by the direct chemical action of such oxidising agents as acid permanganate. Thus, Dr. Dupré has shown in a paper on "Changes in Aeration of Water, as indicating the Nature of the Impurities present in it," that the amount of dissolved oxygen taken up by natural waters, in which bacteria are active, is very much greater than the amount of oxygen which the same waters take up from a solution of permanganate. In other words, one cannot necessarily infer, from the rate of absorption of oxygen from permanganate by an effluent, what the rate of absorption of dissolved oxygen from brook water by the same effluent would be.* Some experiments which we shall have to describe later on will show that this observation by Dr. Dupré has been independently confirmed by both authors of this Report.

It is quite evident from Frankland's experiments, and from the more recent teachings of bacteriology, that the significance of the presence of polluting matters in waters depends not so much upon their exact quantity and chemical composition, but rather on their fermentative properties, the rate at which they will undergo fermentation, under the influence of the mixed organisms natural to river and sea water, and upon the rapidity with which dissolved oxygen will be absorbed during their fermentation.

It is of primary importance, therefore, to ascertain the exact nature of the process of oxidation which occurs during the fermentation of the polluting matters in waters.

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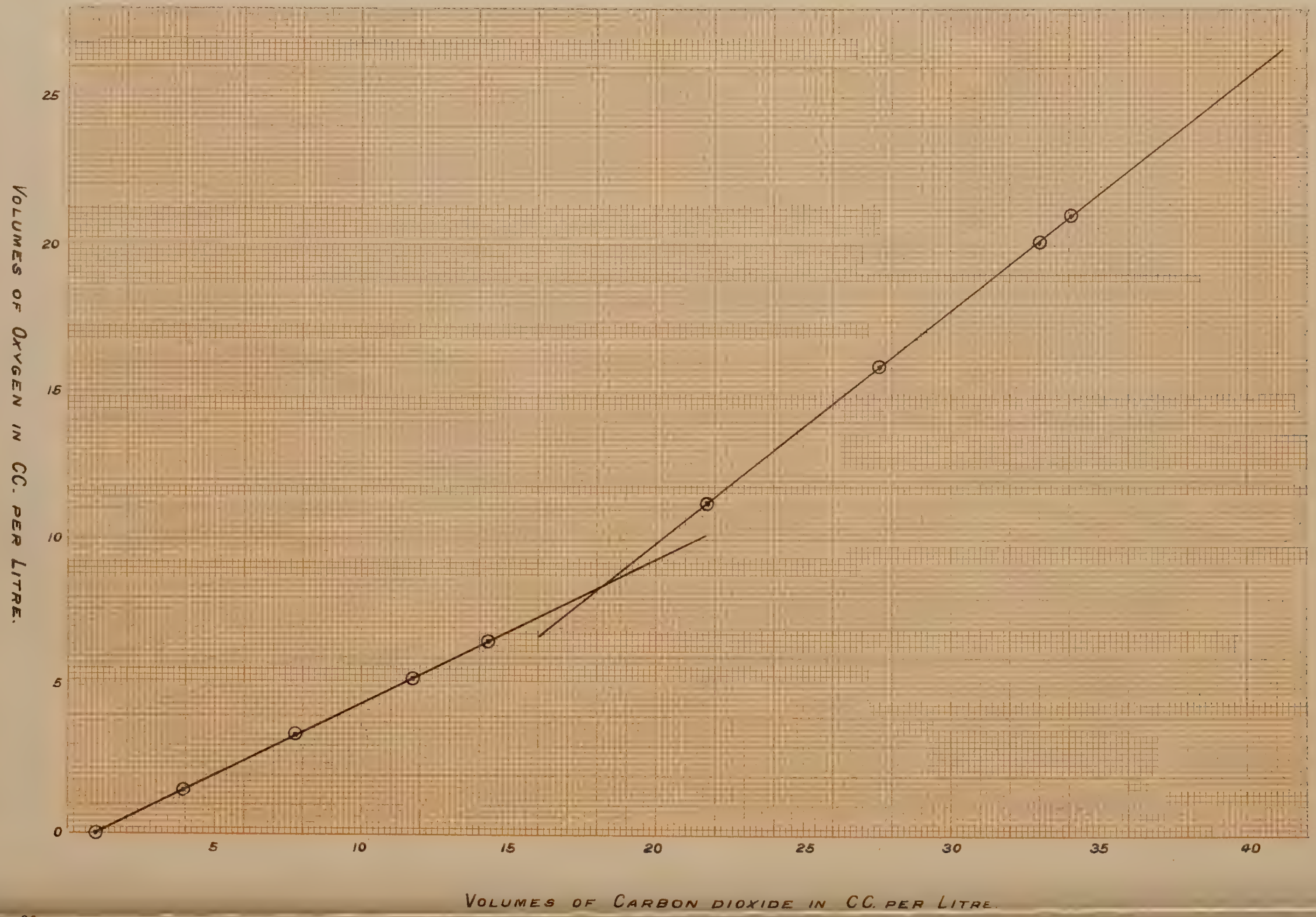
* Supplement to the Report of the Local Government Board for 1884–5. See also Supplement to the Fourth Report of the Royal Commission on Sewage Disposal, Chemical Report by Dr. G. McGowan, Vol. 4, Part 2, p. 327.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

DIAGRAM I. CURVE SHOWING THE VOLUMES OF THE OXYGEN ABSORBED, AND OF CARBON DIOXIDE FORMED, DURING THE AËROBIC FERMENTATION IN DISTILLED WATER, POLLUTED BY KNOWN QUANTITIES OF ROCHELLE SALT.



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FERMENTATIVE CHANGES IN DISTILLED WATER POLLUTED BY KNOWN QUANTITIES OF ORGANIC SUBSTANCES.

One of the authors (Adeney) commenced a careful investigation of this subject as far back as the year 1891, and his results have been published from time to time in the Transactions of the Royal Dublin Society, and in the Proceedings of the Royal Irish Academy.

In one of these papers,* he has given the results of a number of experiments with distilled water separately polluted with known quantities of such simple and definitely constituted substances as Rochelle salt, albumose, urea, and asparagine.

The method of experimenting adopted in these investigations was similar to that employed by Frankland, but somewhat more extended. Solutions of the substance to be experimented with, and of the necessary inorganic salts, were made up to a convenient strength with distilled water. The dissolved gases, inorganic and organic nitrogen (if present), were then determined at the commencement and at the conclusion of the experiment.

For the study of the earlier steps of the fermentation the solutions were preserved in bottles completely filled and carefully stoppered with well ground glass stoppers, the dissolved oxygen in the solution providing a sufficient quantity of that gas for the initial changes. For the study, however, of the complete course of fermentation, it was found necessary to leave air in the bottle, sufficient to provide an adequate supply of oxygen.

For the first-mentioned object a bottle of ordinary description was employed; for the second, one of special form is preferable. A description of it will be found in the part of this section on methods and apparatus. The bottles were kept immersed during an experiment in distilled water, neck downwards, in covered jars.

The germs present in the distilled water, and other substances employed in making up the solutions, were relied upon for setting up fermentation.

1. *Rochelle Salt.*

Intermediate steps of fermentation of Rochelle salt, from start to finish, are illustrated by the experiments recorded in the appended table.

On plotting the carbon dioxide formed with the oxygen absorbed, the course of fermentation is seen to take place in two equal and progressive steps, and the course of each step is approximately represented by a straight line, as is shown by the accompanying diagram.

During the first step, illustrated by the first six experiments, Rochelle salt is evidently, from the respiratory ratio $CO_2 : O_2$ being 2 : 1, converted into potassium sodium malate, carbon dioxide and water; and the malate is oxidised during the second step to carbon dioxide and water, according to the equations—

$$(1) \quad 2\,C_4H_4KNaO_6 + 2\,O_2 = C_4H_4KNaO_5 + 4\,CO_2 + 2\,H_2O + KNaO.$$

$$(2) \quad C_4H_4KNaO_5 + 3\,O_2 = 4\,CO_2 + 2\,H_2O + KNaO.$$

The second stage of change in which the respiratory ratio is 4 : 3 is shown by the experiments Nos. 7, 8, 9, 10, and 11, and in the last of these it will be found that the fermentation of the Rochelle salt was complete. The volume of carbon dioxide formed, and of oxygen absorbed, was 33·95 c.c. and 20·93 c.c., respectively, per litre of water. The volume of carbon dioxide formed represents just about 75 per cent. of the Rochelle salt originally present in solution.

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* "Chemical Changes attending the Aerobic Bacterial Fermentation of Simple Organic Substances Part I.: Urea, Asparagine, Albumose and Rochelle Salt." Proceedings of the Royal Irish Academy 1905.

Several experiments of a similar nature have been made with Rochelle salt by the same author, and they have all been attended with practically similar results.

It may therefore be concluded that in the process of purification of waters polluted by Rochelle salt, the larger portion, 75 per cent., is completely oxidised to carbon dioxide and water, and that this oxidation is brought about by the respiratory or energetic requirements of the organisms, and that the remaining 25 per cent. are taken up by other vital processes of the organisms, principally no doubt of construction and excretion.

TABLE 2.—Experiments made to ascertain the Fermentative Changes which occur under Aerobic Conditions, in Distilled Water Polluted by Known Quantities of Rochelle Salt. The Analyses give the Oxygen consumed and the inorganic products formed by the respiratory changes exerted by water bacteria during the earliest and later stages of their development and activity in solutions containing ·141 grm. Rochelle Salt (equivalent to 44·64c.c. CO_2), and ·1 grm. each, sodium carbonate, potassium phosphate, and potassium chloride, per litre. (*Adeney.*)

The gases are expressed in cc., at O°C. and 760 mm. bar.; the nitrogen as ammonia, and organic nitrogen, as parts by weight per 1000 cc. of water.

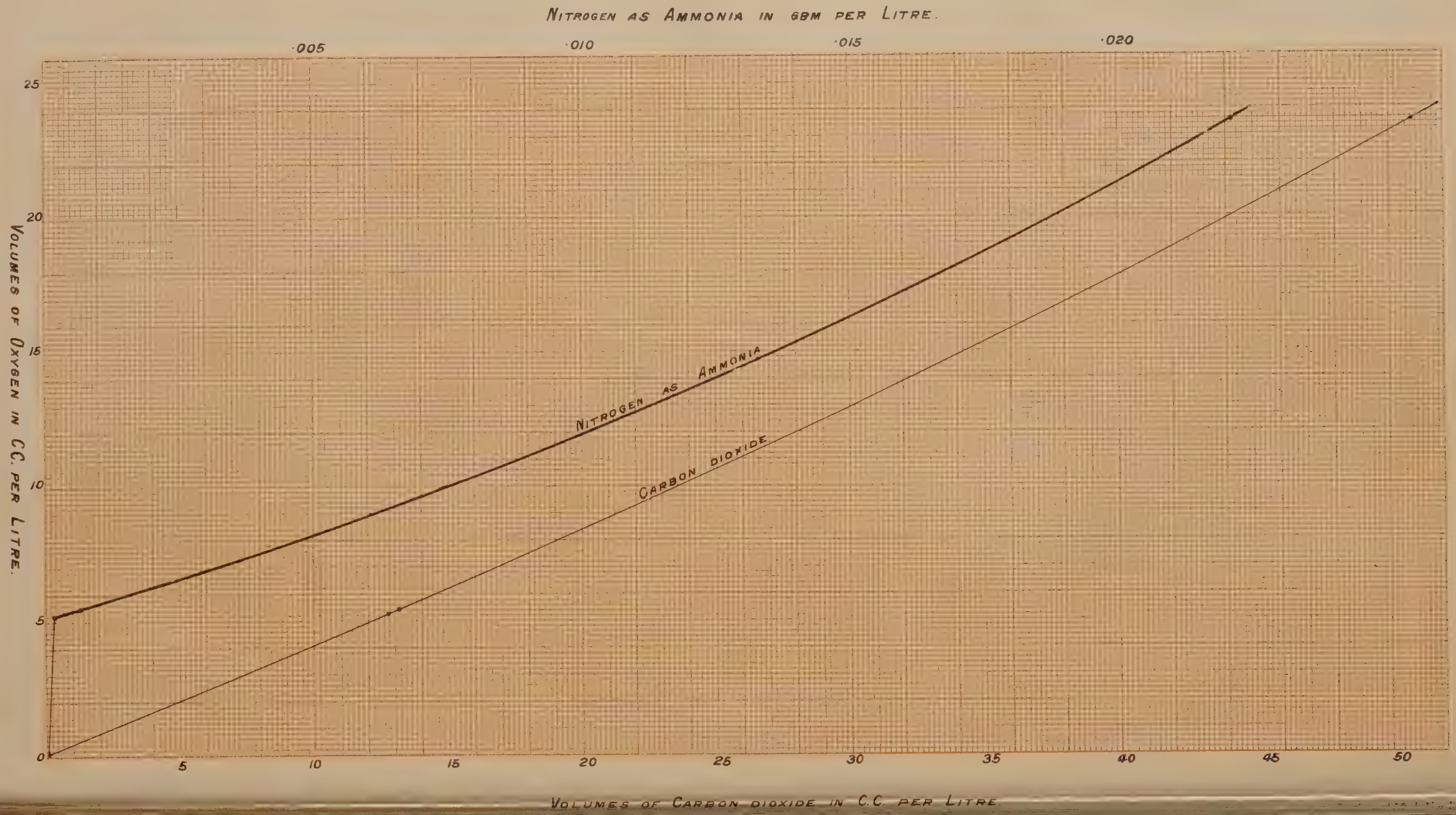
No.	Description of Experiments.	Dissolved Gases			N. as NH_3	Organic N.	Oxygen absorbed from air in flask.	Respiratory change	
		CO_2	O_2	N_2				CO_2 formed.	O_2 absorbed
1	Solution when freshly made - - -	22·45	6·89	13·63	0·0	·0003	–	–	–
2	Portion kept 18 days out of contact with -	23·47	6·89	13·70	0·0	–	–	1·02	–
3	Another portion similarly kept - -	26·58	5·45	13·57	0·0	–	–	4·13	1·44
4	Another portion similarly kept - -	30·11	3·52	13·69	0·0	–	–	7·66	3·37
5	Another portion kept 20 days - - -	34·10	1·63	13·59	0·0	–	–	11·65	5·26
6	Another portion also kept 20 days - -	36·78	0·44	13·61	0·0	–	–	14·33	6·45
7	A portion of No. 4 after further keeping for 38 days in contact with 409·2 c.c. air per litre - - -	44·18	6·38	14·46	trace	–	10·7	21·73	11·21
8	A portion of 6 kept in contact with 507 c.c. air per litre for a further 15 days -	50·01	6·01	13·83	trace	–	15·06	27·56	15·94
9	Portion of 5 kept in contact with 497·7c.c. air per litre for a further 43 days - -	55·29	6·14	15·11	trace	·0002	19·2	32·84	19·95
10	Portion of 3 kept in contact with 430·8c.c. air per litre for a further 47 days - -	55·78	5·98	14·63	trace	·0002	18·27	33·33	19·2
11	Portion, of 2 kept in contact with 241 c.c. air per litre for a further 95 days - -	56·4	4·76	14·99	trace	·00025	18·9	33·95	20·93

2. *Rochelle Salt and Urea.*

On comparing the results which have just been considered with those recorded in the following table it will be noticed that one of the most marked influences of the presence of urea with the Rochelle salt is to set up a rapid fermentation; and yet notwithstanding this, the urea appears to have been but little changed during the earlier steps of the fermentation. Thus in No. 2, although nearly all of the oxygen had been absorbed, only a trace of ammonia had been formed. After three days longer fermentation in another bottle of the solution, No. 3, a small quantity was formed, but this seems to have been the limit for the stage of fermentation which the quantity of dissolved oxygen originally present allowed, for when a third bottle, No. 4, was kept for nearly eleven months, the amount of ammonia found in it was but little more than that in No. 3, which had been kept for only nine days.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Diagram II. Curves showing the quantities of Oxygen absorbed, and of Carbon dioxide, and of Ammonia, formed, during Aerobic Fermentation in Distilled Water polluted by known quantities of Rochelle Salt and of Urea.



When, however, a larger supply of oxygen was provided as in Experiment 5, more advanced stages of fermentation very rapidly set in; and in seven days from the commencement about one-fifth of the urea had been hydrolysed into ammonium carbonate. At the same time the whole of the Rochelle salt had been fermented.

From our knowledge of the behaviour of urea when fermented with other organic substances, we may safely conclude that, in these experiments, it suffered decomposition by enzymic action, and we can quite easily distinguish the products of enzymic change from those due to oxidation. Thus, assuming that the ammonia formed was wholly the result of the hydrolysis of urea, its equivalent of carbon dioxide is 17·54 cc. This leaves a balance of 33·11 cc. of carbon dioxide as due to respiratory changes exerted upon the Rochelle salt. On referring to the experiments with Rochelle salt alone, p. 14, it will be found that the water was polluted by an exactly similar quantity of that substance per litre as the water under discussion; and that the volume of carbon dioxide formed by its complete fermentation was practically the same, 33·95 cc. per litre.

These experiments therefore well illustrate the selective nature of the process of oxidation, for it is evident that it was almost entirely confined to the 75 per cent. of the Rochelle Salt that was converted into carbon dioxide and water.

It is important to note also that, although the Rochelle salt was completely fermented, only 21 per cent. of the urea suffered coincident change. It appears therefore that urea may in some cases suffer enzymic change during fermentation with other organic substances very much more slowly than is commonly supposed.

The volume of oxygen absorbed in the two solutions after completion of the fermentation of the Rochelle salt were not quite similar. Thus with the solution of that substance alone. the volume absorbed was 20 cc. While with the solution containing urea in addition, the volume was 23·35 cc., per litre. It is conceivable that the difference may have been due to a difference of chemical products formed by the vital processes of construction and excretion, since the rate of fermentation was so greatly different in the two solutions.

Table 2a.—Experiments to ascertain the Fermentative Changes which occur under Aerobic Conditions in Distilled Water polluted by Known Quantities of Rochelle Salt and Urea. The results show the Total Atmospheric Oxygen consumed, and the Products formed, by the Respiratory and Enzymic Changes exerted by the Bacteria during the earliest and later Stages of their Development and Activity in Solutions containing 0·225 grms. Urea and 0·141 grms. Rochelle Salt, per litre. (*Adeney*).

No.	Date.	Dissolved Gases.			Nitrogen as
		CO_2 cc.	O_2 cc.	N_2 c.c.	NH_3 grs.
1	At commencement - - - -	19·60	5·34	11·25	0·0002
2	Six days later - - - - -	32·04	0·19	10·69	0·0003
3	Nine days later - - - - -	32·65	0·00	10·79	0·0007
4	Twelve months later - - - -	33·38	0·00	11·05	0·0009
5	Seven days later - - - -	70·25	4·74	13·31	0·0220
	Atmospheres of flask in No. 5:—				
	At commencement - - - -	0·00	160·84	606·34	
	At conclusion - - - - -	0·00	138·09	601·88	

3. *Albumose.*

The experiments which are quoted in the following table were made with distilled water polluted with albumose. This substance was selected as a type of nitrogenous substances, which unlike the native albumins, are fermented under the conditions of these experiments with comparative ease.

TABLE 3.—Experiments to ascertain the Fermentative Changes which occur under Aerobic Conditions in Distilled Water polluted by Known Quantities of Albumose. The Results give the volumes of Oxygen, and the quantities of Inorganic Products, which are respectively consumed and formed, by the Respiratory Changes exerted by Water-bacteria during the earliest and later Stages of their development in Solutions containing 0·05 grm. dry Albumose, equivalent to 28·68 cc. Carbon Dioxide, and 0·0055 grm. Nitrogen, and 0·1 grm. each, Sodium Carbonate, Potassium Phosphate and Potassium Chloride, per litre.

No.	Description of Experiments.	Dissolved Gases.			N as NH_3	Organic N	Oxygen absorbed from air in flask.	Respiratory Changes.		
		CO_2	O_2	N_2				CO_2 formed	O_2 absorbed.	N as NH_3 formed
1	Solution when freshly made -	18·34	7·36	14·69	·00003	·0055	—	—	—	—
2	Portion kept 8 days out of contact with air - -	19·38	6·28	14·57	·0003	—	—	1·04	1·08	·0003
3	Another portion kept 7 days out of contact with air -	20·97	5·01	14·63	·0005	—	—	2·63	2·35	·0005
4	Another portion kept 7 days out of contact with air -	26·27	0·22	14·64	·0016	—	—	7·93	7·14	·0016
5	Another portion kept 9 days in contact with 118 cc. air per litre - - - -	30·76	4·07	15·52	·0024	—	8·9	12·42	12·19	·0024
6	Another portion kept 29 days in contact with 204 cc. air per litre - - - -	40·50	3·80	14·19	·0041	—	19·5	22·16	23·1	·0041
7	A portion from 2 kept 31 days in contact with 310·6 cc. air per litre - - -	41·06	4·75	14·22	·0042	—	21·3	22·74	23·91	·0042
8	A portion from 3 kept 51 days in contact with 419·5 cc. air per litre - - -	40·85	5·49	14·35	·0044	—	20·7	22·51	22·57	·0044
9	A portion from 5 kept 31 days in contact with 189 cc. air per litre - - -	40·71	4·87	14·14	·0044	—	12·3	9·95	11·15	·002

Different steps in the aerobic fermentation of albumose, from commencement to finish, are illustrated by this table.

On plotting together the carbon dioxide and ammonia formed, an approximately straight line is obtained. An approximately straight line is also obtained when the volumes of carbon dioxide formed, and of oxygen absorbed, are plotted together.

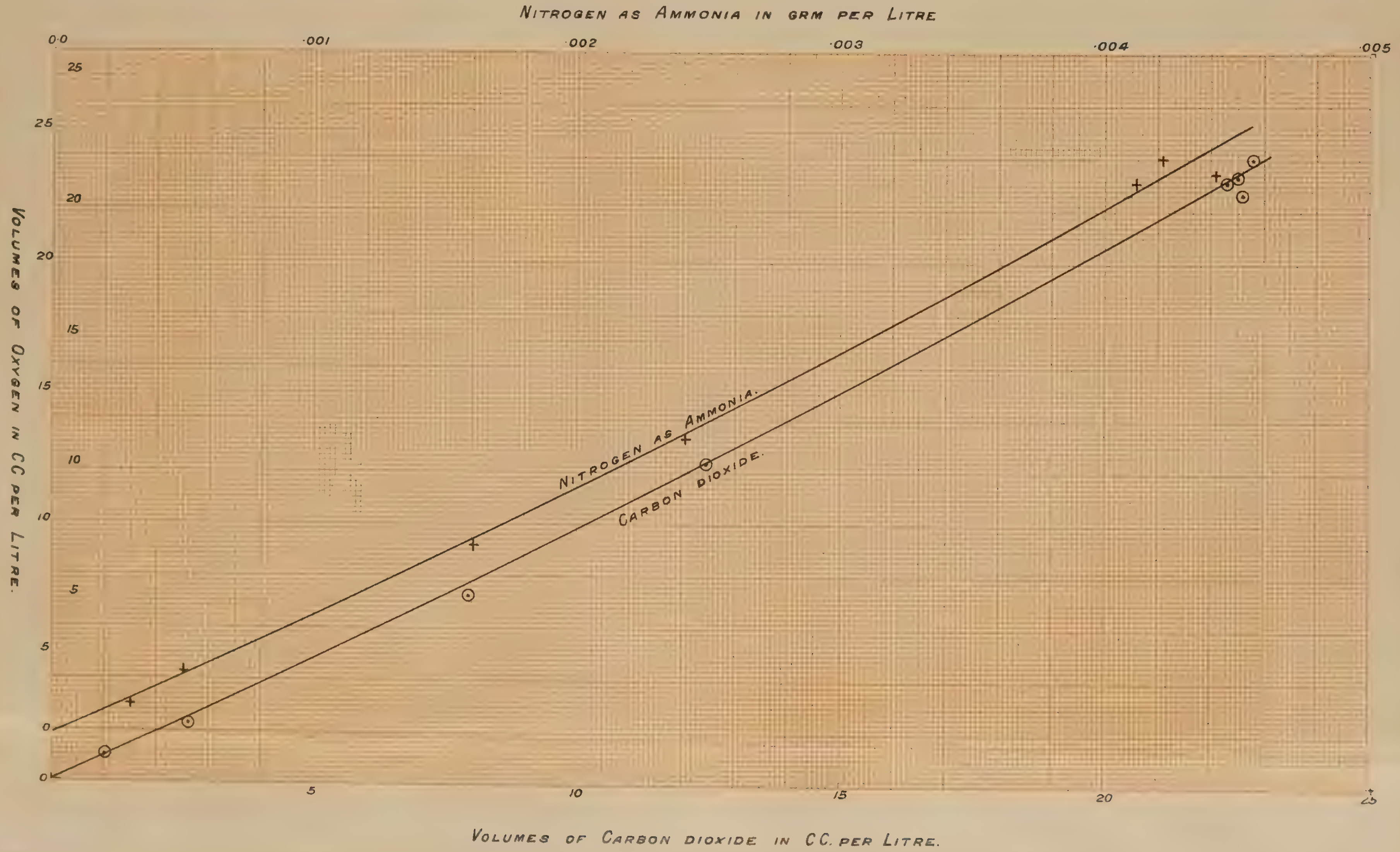
It may therefore be concluded that the oxygen absorbed, and the two inorganic products formed, in these experiments, were the result of complete oxidation, step by step.

The fermentation of the albumose was complete in the experiments Nos. 6, 7 and 8; and the carbon dioxide formed in each of these amounted to 22·16, 22·74, and 22·51 cc. per litre; and the nitrogen as ammonia, to 0·0041, 0·0042, and 0·0044, respectively. The volumes of oxygen absorbed in these experiments were, respectively, 23·1, 23·91, and 22·57. The calculated ratio of CO_2 formed to O_2 absorbed on complete oxidation of albumose is approximately 1 : 1.

The quantities of carbon dioxide and of ammonia formed account for about 78·5 per cent. of the carbon and 76·5 per cent. of the nitrogen, originally present in the albumose.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

DIAGRAM III. CURVES SHOWING THE QUANTITIES OF THE OXYGEN ABSORBED AND OF CARBON DIOXIDE, AND AMMONIA, FORMED, DURING AËROBIC FERMENTATION IN DISTILLED WATER POLLUTED BY KNOWN QUANTITIES OF ALBUMOSE.



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We may therefore conclude that the oxidation process only converts about 78 per cent. of the albumose, to carbon dioxide, water and ammonia, the remaining 22 per cent. was taken up by the processes of construction and excretion.

4. *Asparagin.*

On reference to the table of results with asparagin it will be seen that the experiment, No. 2, was stopped just at the commencement of fermentation, and the results give the chemical changes which were set up during the earliest stages of activity of the organisms; thus only 0·61 cc. oxygen was absorbed, and 1·4 cc. carbon dioxide and 0·001 grm. nitrogen as ammonia were formed.

The results of the two succeeding experiments, Nos. 3 and 4, and of Nos. 12 and 13 indicate slightly more advanced steps of the fermentation, and it will be noticed that the amount of ammonia formed in each of these experiments was very large in comparison with the volumes of carbon dioxide which were also formed. The nitrogen as ammonia amounts to one half the nitrogen originally present in the asparagin, while the carbon dioxide only accounts for one-seventh of the carbon. It may therefore be concluded, having regard to the ease with which asparagin is hydrolysed, that in all four experiments referred to, practically the whole of it was changed by enzymic action into aspartic acid and ammonia, and that the oxidation changes were subsequently exerted upon the aspartic acid so formed, in accordance with the following equations :—

$$(1)\quad C_2H_3(NH_2)\ (CO.NH_2)\ (CO_2H) + H_2O = C_2H_3(NH_2)\ (CO_2H)_2 + NH_3.$$

$$(2)\quad C_2H_3(NH_2)\ (CO_2H)_2 + 3O_2 = 4CO_2 + NH_3 + 2H_2O.$$

From equation (1) it is seen that as a result of hydrolysis one half of the nitrogen in asparagin is retained in the product aspartic acid, and one half goes to form ammonia.

Since in the case of asparagin, ammonia is the sole inorganic product of enzymic change, the whole of the carbon dioxide formed during its fermentation may be regarded as the result of changes due to oxidation.

The ratios of carbon dioxide formed to oxygen absorbed in the experiments Nos. 5 to 10, and 14 to 16, in which a decided excess of oxygen was present during fermentation, are approximately as 4 : 3, which shows that the course of oxidation practically followed that indicated by equation 2.

The course of the fermentative changes are best shown by the accompanying diagram. Thus, when the carbon dioxide and ammonia are plotted together, the course of change is represented by two approximately straight lines, one indicating the enzymic changes principally, the other the after effect of oxidation changes upon the aspartic acid.

When the volumes of carbon dioxide formed, and of oxygen absorbed, are plotted together, two practically straight lines are also obtained.

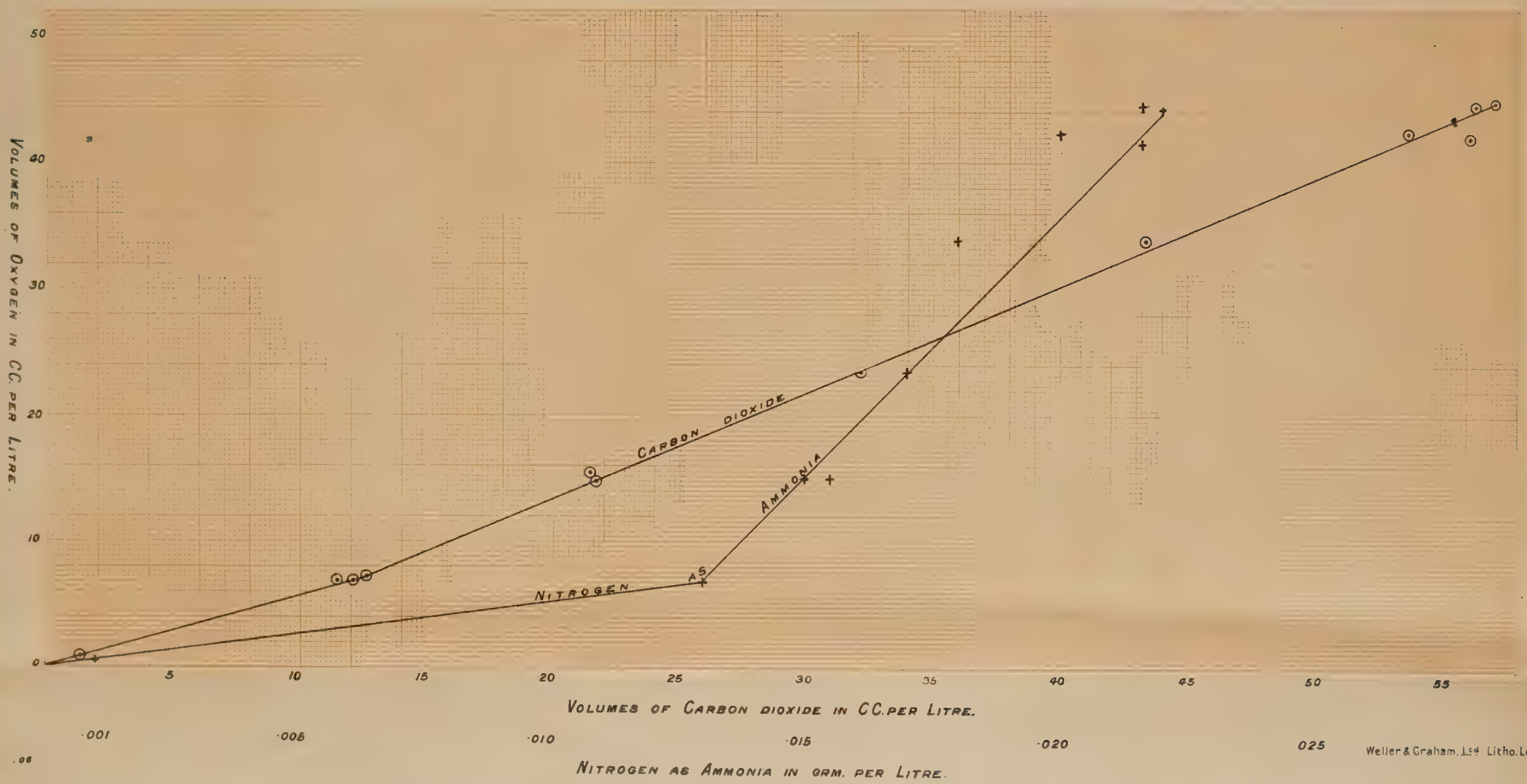
The quantities of carbon dioxide and of ammonia which resulted from the complete fermentation of the solutions of asparagin employed are shown by the results of experiments 9 and 10 with the first solution, and by experiments 14 and 15 with the second solution. They may be taken to be 56·25 cc. carbon dioxide, and 0·01 grm. nitrogen as ammonia, per litre. These quantities represent 67·9 per cent. of the carbon, and 72 per cent. of the nitrogen in aspartic acid.

Hence it may be concluded that asparagin when fermented by mixed water organisms under aerobic conditions, may undergo complete enzymic change into aspartic acid and ammonia during the earliest steps of fermentation, and that the greater portion of the aspartic acid, about 70 per cent., subsequently suffers complete oxidation, and that the remaining 30 per cent. is taken up by the other physiological processes already referred to.

TABLE 4.—Experiments made to ascertain the Fermentative Changes which occur under Aerobic Conditions in Distilled Water, polluted by Known Quantities of Asparagin. The analyses give the Oxygen consumed, and the Inorganic Products formed, by the Respiratory and Enzymic Changes exerted by Water-bacteria during the earliest and later Stages of their Development and Activity in Solutions containing ·123 grm. Asparagin (equivalent to 82·88 cc. CO_2 and ·026 grm. N), and 0·1 grm. each, Sodium Carbonate, Potassium Phosphate, and Potassium Chloride, per litre. (*Adeney.*)

No.	Description of Experiments.	Dissolved Gases.			N as NH_3	Organic N	Oxygen absorbed from air in flask.	Respiratory Changes.			Enzymic Changes.
		CO_2	O_2	N_2				CO_2 formed	O_2 absorbed.	N as NH_3 formed	N as NH_3 formed.
1	Solution when freshly made - - -	17·62	6·94	13·89	·000	·026	—	—	—	—	—
2	Part kept for 3 days out of contact with air - - -	19·02	6·33	13·74	·001	—	—	1·40	0·61	·001	—
3	Another part kept for 5 days - -	29·36	0·0	13·74	·013	—	—	11·74	6·94	·001	·012
4	Another part kept for 5 days - -	29·78	0·0	13·73	·013	—	—	12·16	6·94	·001	·012
5	Another part kept 5 days in contact with 122·4 cc. air per litre - -	39·23	3·35	14·42	·0155	—	12·3	21·61	15·59	·0035	·012
6	Portion of 2 kept 2 days in contact with 271·4 cc. air per litre - -	39·50	5·61	14·82	·0148	—	13·8	21·88	15·1	·0028	·012
7	Portion of 4 kept 3 days in contact with 186·3 cc. air per litre - -	49·83	3·18	14·28	·017	·008	19·8	32·21	23·6	·005	·012
8	Portion of 5 kept 3 days in contact with 356 cc. air per litre - -	60·95	3·89	14·49	·018	·0076	30·2	43·32	34·1	·006	·012
9	Portion of 3 kept 42 days in contact with 324·5 cc. air per litre - -	73·66	3·13	14·22	·0216	·004	38·0	56·04	41·8	·0096	·012
10	Portion of 6 kept 43 days in contact with 631·5 cc. air per litre - -	74·63	4·87	14·37	·0216	·0044	42·6	57·01	44·67	·0096	·012
11	Another solution at commencement -	20·56	7·18	14·26	·000	·026	—	—	—	—	—
12	Part kept 5 days out of contact with air	33·21	0·02	14·25	·013	—	—	12·65	7·15	·001	·012
13	Another part kept for 8 days - -	33·28	0·08	14·25	·013	—	—	12·72	7·08	·001	·012
14	Portion of 12 kept 22 days in contact with 304 cc. air per litre - - -	76·81	2·79	14·98	·022	·004	40·0	56·25	44·4	·01	·012
15	Portion of 14 kept 23 days in contact with 536·3 cc. air per litre - -	76·50	6·77	14·40	·022	·004	6·6	—	2·6	—	—
16	Portion of 13 kept 48 days in contact with 561·4 cc. air per litre - -	74·13	5·30	15·12	·020	—	40·6	53·57	42·5	·008	·012

DIAGRAM IV. CURVES SHOWING THE QUANTITIES OF THE OXYGEN ABSORBED AND OF CARBON DIOXIDE, AND OF AMMONIA, FORMED, DURING AËROBIC FERMENTATION IN DISTILLED WATER POLLUTED BY KNOWN QUANTITIES OF ASPARAGIN



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5. *Urea.*

The behaviour of urea, when present with other organic substances undergoing bacterial fermentation, is well-known. As shown by the experiments which have been described, p. 15, it undergoes hydrolysis to ammonium carbonate. When, however, it is present in distilled water, unmixed with any other organic substance, its behaviour is different and is instructive. A large proportion of it then undergoes chemical change due to the respiratory and other vital processes of the organisms, and only a small proportion undergoes hydrolysis.

The results of a number of experiments with distilled water polluted by this substance are given in following table :—

Table 5.—Experiments made to ascertain the Fermentative Changes which occur under Aerobic Conditions, in Distilled Water Polluted by Known Quantities of Urea. The analyses give the Oxygen consumed, and the Products formed, by the Respiratory and Enzymic Changes exerted by the Bacteria during the earliest Stages of their Development and Activity in Solutions containing 0·225 grm. Urea, and 0·1 grm. each of Potassium Phosphate, Potassium Chloride and Sodium Carbonate, per litre (*Adeney*). The Gases are stated in c.c. at N.T.P., and the Organic Nitrogen and Inorganic Nitrogen Compounds in grms., per litre :—

	Dissolved Gases.			Nitrogen as		
No.	CO_2	O_2	N_2	Organic	NH_3	N_2O_3
1	19·63	6·99	13·74	0·105	0·0001	0·0
2	20·53	6·42	13·56	0·105	0·0003	trace
3	23·19	3·05	13·50	—	0·0032	0·00148
4	29·88	0·01	13·47	—	0·0108	0·00247
5	42·22	0·00	13·40	0·077	0·026	0·00244

No. 1. Analysis of solution at commencement of experiment.
No. 2. Analysis of solution five months later.
No. 3. Analysis of a portion of solution from No. 2. after allowing it to ferment eight days longer.
No. 4. Analysis of a portion of the solution from No. 3 after allowing it to ferment three days longer.
No. 5. Analysis of another portion of original solution after keeping for five months.

On comparing the results of No. 3 with those of No. 1 in this table, it appears that ·00148 grm. of nitrogen as nitrous anhydride, ·0031 grm. of nitrogen as ammonia, and 3·56 cc. of carbon dioxide, were formed, while 3·94 cc. oxygen were consumed.

The proportion of nitrogen as nitrous anhydride to that as ammonia is so nearly as 1 : 2 that it may be fairly assumed that this first step of fermentation consisted almost entirely of a direct oxidation according to the equation—

$$(1)\quad 3CON_2H_4 + 3O_2 = 3CO_2 + N_2O_3 + 4NH_3.$$

It will be seen from this equation that the volume of carbon dioxide formed is equal to that of the oxygen consumed, one half of the latter being taken up to form nitrous anhydride, and one half to form carbon dioxide. On reference to the analysis of No. 3 it will be seen that the volume of carbon dioxide formed was very nearly equal to the volume of oxygen consumed.

Assuming this equation to indicate correctly the process of oxidation, we may differentiate the products due to it from those due to enzymic action in the later stages of fermentation. Thus, the volume of oxygen equivalent to the nitrogen as nitrous anhydride may be obtained by calculation ; then twice that volume equals the carbon dioxide formed at the same time. The remainder of the carbon dioxide may then be taken as due to enzymic action ; and the nitrogen as ammonia equivalent to it may be calculated according to the equation—

$$(2)\quad CON_2H_4 + H_2O = CO_2 + 2NH_3.$$

Table 6.—Showing the Percentages of the Products, recorded in Table 5, which were due to Respiratory Changes, and those which were due to Enzymic Change, the Total Carbon Dioxide and Inorganic Nitrogen Compounds being taken each as 100. (*Adeney.*)

Results of Respiratory Changes.					Enzymic Changes.		Oxygen absorbed by other Physiological Processes.
No.	CO_2	NH_3	N_2O_3	O_2 absorbed	CO	NH_3	——
3	100·0	67·7	32·3	89·9	0·0	0·0	10·15
4	57·7	37·5	18·8	84·6	42·3	41·0	15·45
5	25·9	17·2	8·6	83·5	74·1	73·8	16·54

It will be observed that the division of the fermentative products between the processes of respiratory and enzymic changes, in accordance with the above equations (1 and 2), is shown to be justified by the fact that the inorganic products are nearly all accounted for in the table.

The oxidation changes were similar in degree in the two experiments 4 and 5; but the enzymic changes were very different. This was no doubt due to the solution in the latter experiment being kept for some time after aerobic conditions had ceased.

The next series of experiments with this substance were carried out with the object of studying more advanced stages of fermentation; and the following results were obtained—

Table 7.—Experiments made to ascertain the Fermentative Changes which occur, under Aerobic Conditions, in Distilled Water Polluted by Known Quantities of Urea.* The analysis give the Results of more advanced steps in the Fermentation of Urea under Complete Aerobic Conditions.—(*Adeney.*)

No.		Atmosphere of the Flasks.			Dissolved Gases.			Combined Nitrogen.			The Composition of the Gases in the Air-spaces at Commencement.		
		CO_2 c.c.	O_2 c.c.	N_2 c.c.	CO_2 c.c.	O_2 c.c.	N_2 c.c.	Organ. grs.	NH_3 grs.	N_2O_3	No.	Oxygen c.c.	Nitrogen c.c.
*6	5 months after commencement	0·00	52·36	304·23	55·17	2·20	13·35	·0590	·0360	·01145	6	80·20	302·53
7		0·71	25·63	269·26	84·17	1·34	13·26	·0140	·0675	·01850	7	71·18	268·52
8		1·91	25·37	347·94	86·30	1·41	13·46	·0195	·0500	·02590	8	92·31	348·19
9		5·84	31·40	412·55	76·12	2·00	13·27	·0125	·0500	·02960	9	109·25	412·03

* Note.—For the composition of the solution at the commencement of this series of experiments, *see* No. 1, Table 5.

The changes in composition of the gases in the atmosphere of the flasks, and in the solutions, indicated in the preceding table, may be summarised as follows :—

No.	CO_2	O_2	N_2
6	+ 35·54	– 32·63	+ 1·31
7	+ 65·25	– 51·20	+ 0·26
8	+ 68·58	– 72·52	– 0·53
9	+ 62·33	– 82·84	+ 0·05

SHOWING THE QUANTITIES OF OXYGEN ABSORBED, AND OF CARBON DIOXIDE, AMMONIA AND NITROUS NITROGEN, FORMED, DURING THE FIRST STAGE OF AËROBIC FERMENTATION IN DISTILLED WATER POLLUTED BY KNOWN QUANTITIES OF UREA.

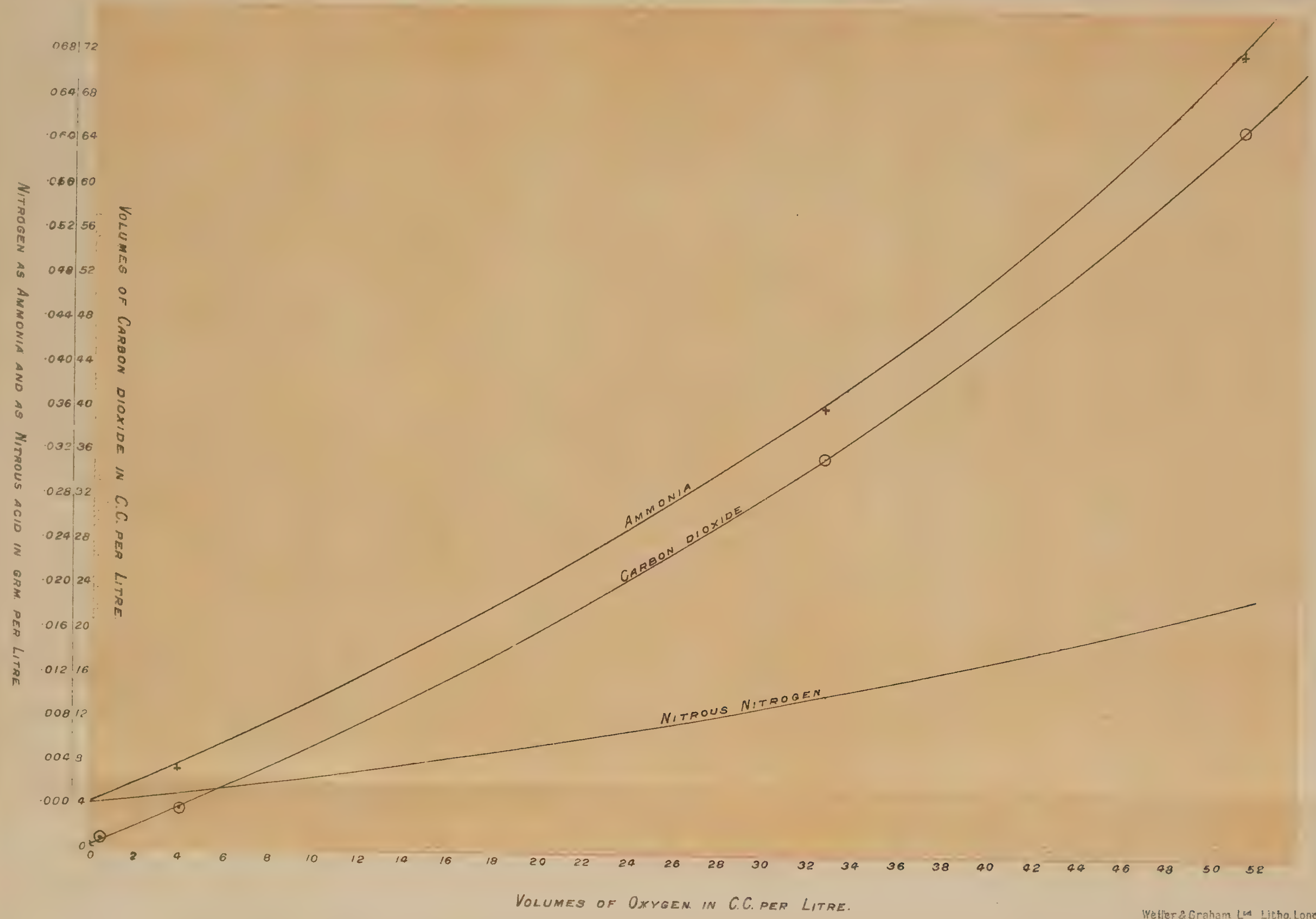

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Table 8.—Stating the Results due to Respiratory and Enzymic Changes respectively, in Percentages, as in Table 6. (*Adeney.*)

Results of Respiratory Changes.					Enzymic Changes.		Oxygen absorbed by other Physiological Processes.
No.	CO_2	NH_3	N_2O_3	O_2	CO_2	NH_3	———
6	77·0	48·5	24·3	83·9	23·0	21·6	16·1
7	67·8	43·1	21·5	86·5	32·2	30·7	13·5

The figures in the foregoing tables again prove that the inorganic products are approximately accounted for when distributed in accordance with the above equations 1 and 2; and they afford additional evidence that the principle upon which the division has been made is well founded.

It is evident from the analytical results recorded for No. 6, that the urea originally present in solution had by no means undergone complete fermentative change.

Of the total products formed in this experiment, 77 per cent. of the total carbon dioxide was the result of the oxidation and 23 per cent. the result of enzymic change; while, of the total inorganic nitrogen products, 72·81 per cent. was the result of oxidation, and 21·58 of enzymic change, leaving 5·6 per cent. of these products unaccounted for.

Of the oxygen consumed, 83·91 per cent. was taken up by the oxidation process, and 16·09 per cent. by other vital processes.

On comparing together the analytical results recorded for the next three experiments, Nos. 7, 8 and 9, it is evident that No. 7 marks the point when the fermentative change of the urea originally present had just been completed; while Nos. 8 and 9 mark well advanced steps in the ordinary nitrification of the ammonia.

In the case of No. 7, 67·8 per cent. and 64·6 per cent., respectively, of the total carbon dioxide and inorganic nitrogen products were the result of oxidation; and 32·2 per cent., and 30·7 per cent., respectively, of the same products were the result of enzymic action, leaving in the case of the latter products 4·7 nitrogen as ammonia unaccounted for.

Of the oxygen consumed, 86·5 per cent. were taken up by the respiratory changes, and 13·5 per cent. by other physiological or vital processes.

Although Experiment 7 illustrates the complete fermentation of the urea, the total volume of carbon dioxide formed only accounts for 77·96 per cent. of the carbon, and the total inorganic nitrogen products in 81·9 per cent. of the nitrogen in the urea originally present. It may, therefore, be assumed that the balance of carbon, nitrogen, and atmospheric oxygen, viz., 22·04, 18·1, and 13·5, per cent., respectively, were taken up by the vital processes of construction and excretion.

Conclusions to be drawn from the foregoing Experiments.

The experiments, which have just been considered, show with sufficient definiteness the nature of the process of oxidation, which is set up in polluted waters during purification by bacterial fermentation under aerobic conditions. It is one of a number of physiological processes concerned in the metabolism of the water bacteria, and may be regarded as analogous to that of respiration in higher vegetable systems.

The results of the experiments prove that the greater portion, 70 to 80 per cent., of the organic substances undergoing fermentation are affected by the process, and that these portions are completely oxidised to the ultimate inorganic products carbon dioxide and water, and also ammonia when nitrogenous organic substances are present. The oxidation may be complete, step by step, during the fermentation, as in the case of albumose or partial in the earlier stage, and complete in the later stage, of the fermentation, as in the case of Rochelle salt.

The ratio of carbon dioxide formed to oxygen absorbed varies with the composition of the substance undergoing fermentation. Thus for asparagin it is approximately 4 : 3; for Rochelle salt it is approximately 2 : 1 for the first half of the fermentation, and 4 : 3 for the second half; for albumose it is approximately 1 : 1.

It is evident from these ratios that the oxygen absorbed during fermentation was nearly, if not wholly, taken up by the respiratory process in each case, and that the oxidation of the organic substances which were effected by the respiratory process was complete; it only required the presence of active bacteria to bring it about.

Although for the reasons stated the oxygen absorbed during fermentation may be regarded as mainly taken up by the respiratory process, the experiments with urea show that quite considerable proportions, about 16 per cent., may be taken up by other physiological processes under the exceptional circumstance of the absence of all other organic substances. So too in the case of the fermentation of ammonia in the absence of organic substances, the experiments on which subject will be found recorded in Table 19, pp. 39 and 40. They show that as much as 19 per cent. of the total oxygen absorbed was taken up by processes other than that of respiration. It is therefore possible that this may occur, although to a less extent, in the case of other substances in proportions varying with the composition of the organic substances undergoing fermentation.* It may, however, be assumed from the experiments with Rochelle salt, asparagin, and albumose, that these proportions will always be small in the case of ordinary polluted waters, and that it will be probably safe to neglect it, and to regard the whole of the oxygen absorbed during fermentation as taken up by the respiratory process. It is obviously improbable that either urea or ammonia could ever occur in ordinary polluted waters unassociated with organic substances.

The same experiments also show that the rate of oxidation is profoundly affected by two fundamental conditions, viz., the composition of the organic substances in solution in the water, and the action of enzymes; the bacteria being similar in kind and in activity in both solutions. Thus Rochelle salt when it is the only organic substance present in the water, is very slowly attacked by water bacteria. In the experiments for instance recorded in Table 2 the fermentation of the distilled water solution containing ·141 grm. of that substance per litre extended over sixty days, while in another solution similar in all respects, except that it contained urea in addition to Rochelle salt, Table 3, the fermentation was complete within seven days. The urea was not appreciably affected by the respiratory process, and only about one-fifth of the quantity originally present was hydrolysed to carbonic acid and ammonia by enzymic action.

Again asparagin, when in solution by itself is also very slowly fermented, but when associated with other bodies such as Rochelle salt, both these substances are fermented with extreme rapidity, the bacteria being similar in kind and activity in both cases (*see* Table 9).

As regards the action of enzymes, they are shown by the same experiments to be intimately associated with the respiratory process in breaking down the organic substances in polluted water. The chemical changes effected by them are principally hydrolytic, and the products are generally simplifications of the original body, and these undergo further fermentative changes. Only in the case of urea do they effect a complete change to simple inorganic products, carbon dioxide and ammonia.

Sometimes the substance is rapidly and completely hydrolysed at the commencement of the fermentation, as in the case of asparagin, which is converted into ammonia and aspartic acid, and the fermentative changes are subsequently exerted upon the latter product.

When urea is mixed with Rochelle salt, as in the experiments already referred to, it is not apparently affected by enzymic action during the earlier steps of the fermentation, but only after that has been well established, when in other words the bacteria have become very active, and then it appears from the experiments recorded in Table 2*a*, p. 15, that it is slowly hydrolysed into carbon dioxide and ammonia.

There are some organic substances, *e.g.*, native albumins, fats, vegetable oils, etc., which apparently must undergo enzymic change before they can be rapidly attacked by the fermentative processes of water bacteria, and it may be concluded that such bodies can consequently only be rapidly fermented in waters containing large numbers of bacteria in a state of activity, or after they have been previously changed by enzymic action. Thus native albumins may be converted into albumoses by enzymic action, and these subsequently rapidly fermented by water bacteria. Fats and vegetable oils may likewise be changed into fatty acids and glycerine, and these be subsequently fermented.

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* *See* also the experiments with Rochelle salt alone and with urea, pp. 13–15.

In the case of the experiments with the more complex solution of Rochelle salt and asparagin, which will be found recorded in Table 9, p. 24, it is evident from the respiratory ratios which were determined during intermediate steps of the fermentation, that both substances simultaneously suffered partial oxidation at first and that the partially oxidised products were subsequently completely oxidised during later steps of the fermentation. The ratios were 2 : 1 at first, then 1·85 : 1, and finally 1 : 1.

In the case of sewage matters the true respiratory ratio cannot be thus definitely determined, owing to their complex composition, to possible and unknown changes by enzymic action, and to the probability of their having undergone the earlier steps of fermentation before it has been possible to examine them. The ratio, however, of the total volume of carbon dioxide formed to the oxygen absorbed during the fermentation in sewage seems to be fairly constant, judging from the determinations which have so far been made, and which will be found recorded in subsequent portions of this section ; it is a little greater than 1 : 1.[†]

The chemical changes which are brought about by the respiratory process and by enzymes may be regarded as yielding a continual supply of energy to the organisms. They account for the complete oxidation of purification of 70 to 80 per cent. of the organic substances originally present in the polluted water, and of a still higher proportion, if urea be present in distinct quantities, since this substance would then be hydrolysed into ammonia and carbon dioxide by enzymic action.

As regards the remaining portions of the organic substances originally present in the polluted water, it is obvious that they must be taken up by other physiological processes. It is impossible to attempt to detail these processes, and it is unnecessary. It is sufficient for the study of polluted waters to regard them as together exercising one function, viz., the synthesis of the constructive material required for the growth and multiplication of new organisms ; and at the same time to recognise that there must result from these synthetical processes waste or bye-products, which may be termed excretory substances.

These last named bodies consist largely if not wholly of coloured substances, precisely similar in chemical and physical properties to the colouring matters of peat and of the humus of garden soil. They impart to fermented waters various tints, from yellowish green to brown, according to the quantities of organic substances which have been fermented. They exercise an extremely important function in the subsequent fermentation of ammonium compounds to nitric acid, and will be fully dealt with in a subsequent part of this section.

Rideal has noticed the formation of humus-like bodies which result from the anaerobic fermentations of organic substances that occur in septic tanks,* and they no doubt are also bye-products from synthetical processes in anaerobic fermentation.

PART II.

THE CHEMICAL CHANGES WHICH OCCUR IN POLLUTED WATERS WHEN UNDERGOING PURIFICATION BY AEROBIC FERMENTATION TAKES PLACE IN TWO DISTINCT AND PROGRESSIVE STAGES.

It will have been noticed that in all the experiments so far dealt with, save those with urea, no nitrates nor nitrites have appeared amongst the products of fermentation. This arises from the fact that the experiments were stopped before nitrification had commenced, and not from the absence of nitrifying organisms.

Under the conditions which obtain when the supply of oxygen during fermentation is wholly drawn from that dissolved in the water, the rate of change is necessarily extremely slow, and the course of change then proceeds in two distinct and progressive stages, first the organic matters are completely changed as already indicated, and converted into carbon dioxide, water, ammonia and excretory substances, then the two last named bodies are further fermented, the products being nitrites, nitrates and comparatively small quantities of carbon dioxide.

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* "Sewage and sewage purification," p. 77.

[†] See pp. 28–30.

The two stages of change are illustrated by the experiments which we quote in the following table.

TABLE 9.—Experiments showing that the Complete Purification, by Aerobic Fermentation of Water, Polluted by Known Quantities of Rochelle Salt and Asparagin, takes place in two distinct and progressive stages. (*Adeney.*)

Solution A contained 0·066 grammes asparagin,
„ „ 0·141 „ Rochelle salt, per litre.
„ „ 0·1 „ potassium phosphate.

No. of Experiment.	Date of Commencement and of Conclusion of Experiment.	Nature of Experiment.	CO_2.	O_2	N_2.	N as NH_3.	N as N_2O_3.	N as N_2O_5.	Remarks.
1	Mar. 6, 1894	Solution A, as above (in tap water) - -	11·21	7·86	15·93	0·0	0·0	0·0001	
	„ 12, „	Same after fermentation -	26·73	0·05	16·13	0·0093	0·0	0·0	Liquid very turbid, but free from odour.
		Differences -	+ 15·52	− 7·81	—	+ 0·0093	—	—	
2	„ 12, „	Remainder of the preceding solution, after fermentation re-aerated, = A′ -	26·62	7·36	15·14	0·0095	0·0	0·0	
	„ 13, „	A′ after fermentation, I. - -	37·16	1·52	15·30	0·0108	0·0	0·0	Ditto
	„ 14, „	Another bottle of A′ after fermentation from March 12, II. -	40·15	0·05	15·16	0·0102	0·0	0·0	Ditto
		Differences I. -	+ 10·54	− 5·84	—	+ 0·0013	—	—	
		Differences II. -	+ 13·53	− 7·31	—	+ 0·0007	—	—	
3	„ 14, „	Remainder of solution A′ (Mar. 14) diluted with equal volume of distilled water and aerated = A′/2 - -	20·62	7·81	16·11	0·0032	0·0	0·0	
	„ 19, „	Same after fermentation I. -	32·21	1·72	15·92	0·0045	0·0	0·0	Faint sour odour, turbid.
	„ 19, „	Another bottle of A′/2 after fermentation I. -	32·01	1·56	15·89	0·0038	0·0	0·0	Ditto
		Differences I. -	+ 11·59	− 6·09	—	+ 0·0013	—	—	
		Differences II. -	+ 11·39	− 6·25	—	+ 0·0006	—	—	
4	„ 19, „	Remainder of liquid from two preceding analyses mixed and aerated -	29·06	7·56	15·60	0·0040	0·0	0·0	
	Apl. 12, „	Same after fermentation -	36·75	0·00	15·40	0·0056	0·0	0·0	No distinct odour.
		Differences -	+ 7·69	− 7·56	—	+ 0·0016	—	—	
5	„ 12, „	Remainder of preceding solution re-aerated - -	31·42	7·04	13·98	0·004	0·0	0·0	

TABLE No. 9—*continued.*

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Nature of Experiment.	CO$_2$.	O$_2$.	N$_2$.	N as NH$_3$.	N as N$_2$O$_3$.	N as N$_2$O$_5$.	Remarks.
	Aug. 1, 1894	Same after fermentation -	35·22	0·0	14·10	0·0044	0·0015	0·0	Quite free from odour
		Differences -	+ 3·80	– 7·04	—	+ 0·0004	+ 0·0015	—	
6	„ 1, „	Remainder of preceding solution diluted with an equal bulk of distilled water and aerated -	17·033	6·11	12·67	0·0022	0 0009	0·0	
	Jan. 4, 1895	Same after fermentation I. -	16·69	0·07	12·55	0·0	trace.	0·002	
	„ 14. „	Another bottle of same after fermentation II. -	16·79	0·05	12·63	0·0	0·00016	0·00204	
		Differences I. -	– 0·34	– 5·94	—	– 0·0022	– 0·0009	+ 0·002	
		Differences II.-	– 0·24	– 5·96	—	– 0·0022	– 0·00074	+ 0·00204	
1a.	Mar. 6, 1894	Solution A. from Table VII., diluted with tap-water in the proportion of 1 : 9 vols. - -	4·65	7·86	15·93	0·0	0·0	0·001	
	„ 15, „	Same after fermentation -	9·32	4·52	15·75	0·0008	0·0	0·0001	Slightly turbid, no odour
		Results of fermentation -	+ 4·67	– 3·34	—	+ 0·0008	—	—	
2a.	May 15, „	Remainder of preceding solution aerated - -	9 05	7·35	15·64	0·0008	0·0	0·0001	
		Same after fermentation -	12·28	2·06	15·47	0·0	0 0	0·0015	
	May 17, „	Results of fermentation -	+ 3·03	– 5·19	—	– 0·0008	—	+ 0·0014	
3a.	Mar. 6, „	Solution A from Table VII., diluted with tap-water in the proportion of 1 : 19 vols. I. - -	4·29	7·86	15·93	0·0	0·0	0·0001	
	„ 20, „	Same after fermentation II. -	6·86	5·63	15·94	0·0008	0·0	0·0001	
		Results of fermentation -	+ 2·57	– 2·23	—	+ 0·0008	—	—	
4a.	„ 20, „	Remainder of preceding solution immediately transferred to a smaller bottle, and after further fermentation again analysed -	8·04	4·02	15·86	trace.	0·00048	0·00042	
	Apl. 30, „	Results of fermentation (from II.)	+ 1·18	– 1·63	—	– 0·0008	+ 0·00048	+ 0·00032	

The volumes of oxygen absorbed, and of products formed, during each step of the first and second stages of fermentation, represented by the experiments, may be tabulated as follows :—

——	CO_2	O_2	Ratios.	Nitrogen as		
				NH_3	N_2O_3	N_2O_5
First Stage—						
Experiment 1 - - - -	15·52	7·81	2 to 1	·0093	0·0	0·0
„ 2 - - - -	13·53	7·31	1·85 to 1	·0007	0·0	0·0
„ 3 (× 2) - - -	22·98	12·34	1·86 to 1	·0019	0·0	0·0
„ 4 (× 2) - - -	15·38	15·12	1 to 1	·0032	0·0	0·0
Totals - - - -	67·41	42·58	1·58 to 1	·0151	0·0	0·0
Second Stage—						
Experiment 5 (× 2) - - -	7·6	14·08	—	(·0008)*	·003	0·0
„ 6 (× 4) - - -	–1·24†	23·80	—	·0	·0	0·0081
Totals - - - -	7·6	37·88	—	—	—	0 0081

These figures show that a great portion of the nitrogen was quickly converted into ammonia, so that it may be assumed that the asparagin was rapidly hydrolysed by enzymic action into aspartic acid and ammonia, just as in the case of the simple solution of that substance.

It then appears from the ratios of carbon dioxide formed to oxygen absorbed, and also from the ammonia formed, that the aspartic acid and the Rochelle salt jointly suffered respiratory changes, which were partial at first but complete at later stages of the fermentation.

67·41 c.c. of carbon dioxide were formed on the completion of the fermentation. This volume represents 78·96 per cent. of the organic carbon originally present in the solution.

Apparently, from the quantities of ammonia shown by the experiments to have been formed, all the nitrogen originally present in the asparagin was changed into ammonia. This, however, is probably only apparent. From the nature of the experiments the errors attending the ammonia determinations would be appreciable in the aggregate.

The succeeding experiments 5 and 6 illustrate the course of change which takes place in the second stage of fermentation. It will be observed that the products of this stage, nitrous and nitric acids, do not appear until the organic substances have been completely broken down, and when consequently the formation of carbon dioxide rapidly diminishes. During the last step of the second stage represented by Experiment 6, no carbon dioxide was formed, but small quantities were actually fixed. We shall deal with the question involved in this point later on.

The course of change in these experiments is more conveniently indicated by the curves which will be found in the appended diagram.

On referring to the results of the diluted portions of A, A 10, and A 20, it will be observed that the effect of dilution is to mask, if not to prevent, the formation of intermediate organic products of oxidation, which are so noticeable with the undiluted liquid A. Thus, on summing the results as before, we get—

Experiment.	CO_2.	O_2=to N_2O_3.	O_2=to N_2O_5.	O_2 absorbed.
A/10 1a (× 10) - - - - - - -	46·7	0·0	0·0	33·4
„ 2a (× 10) - - - - - - -	30·3	0·0	44·66	51·9
Totals - - - - - -	77·0	0·0	44·66	85·3
A/20 3a (× 20) - - - - -	51·4	0·0	0·0	44·6
„ 4a (× 20) - - - - -	23·6	22·94	20·42	32·6
Totals - - - - - - -	75·0	22·94	20·42	77·2

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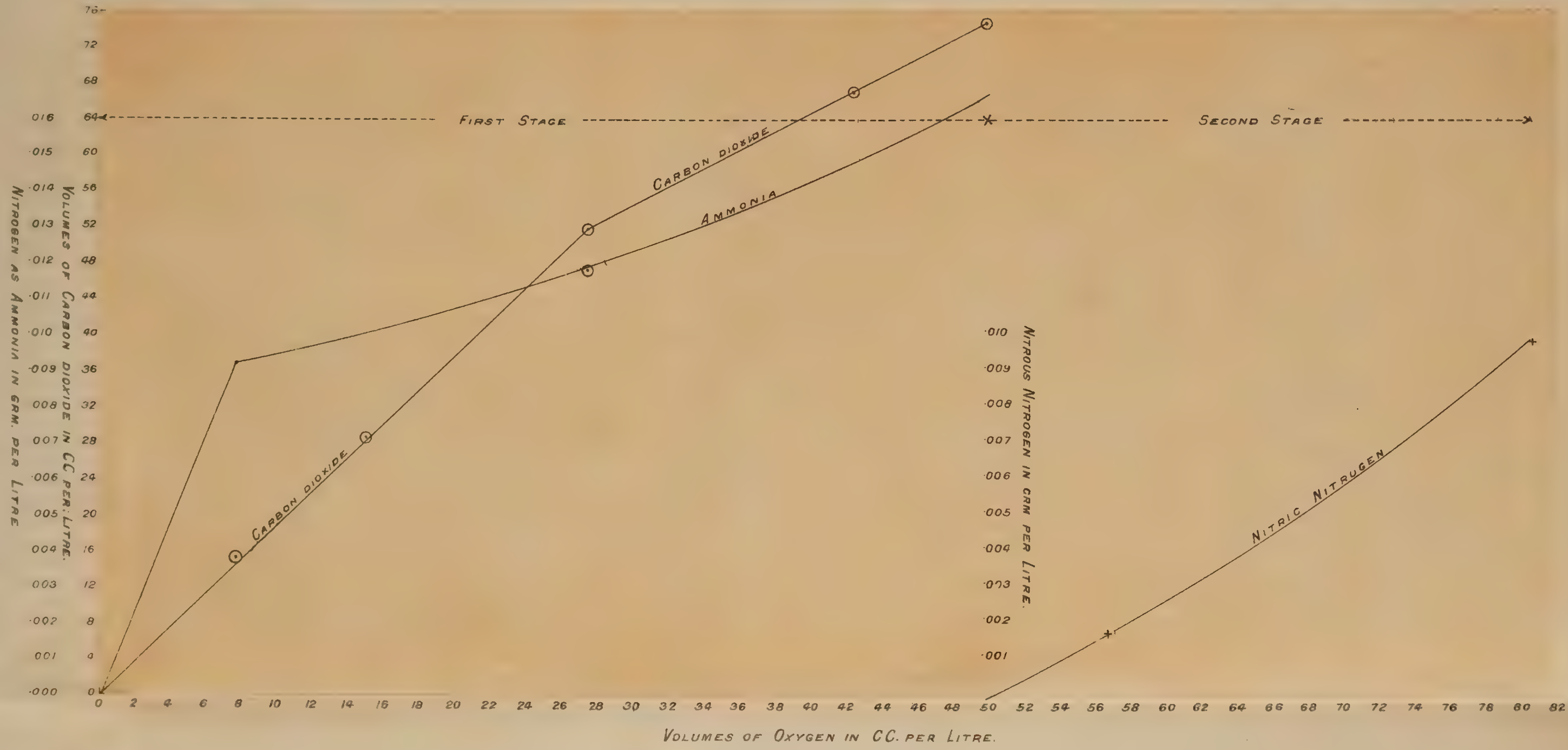
* Note that the formation of small quantities of ammonia in this experiment proves that at its commencement the first stage of fermentation had not been quite completed.

† Note that in this experiment small quantities of carbon dioxide were fixed.

DIAGRAM [illegible] CURVES SHOWING THE QUANTITIES OF OXYGEN ABSORBED, AND OF CARBON DIOXIDE AND AMMONIA FORMED, DURING THE FIRST STAGE, AND OF OXYGEN ABSORBED, AND OF NITROUS AND NITRIC NITROGEN FORMED, DURING THE SECOND STAGE, OF AËROBIC FERMENTATION IN DISTILLED WATER POLLUTED BY KNOWN QUANTITIES OF ROCHELLE SALT AND OF ASPARAGINE



NOTE:– THE NITROUS NITROGEN IS TAKEN AS EQUIVALENT TO 3/5THS NITRIC NITROGEN.

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The ratio of carbon dioxide to oxygen in Experiment 1a was 1·4 to 1, and in Experiment 3a, 1·15 to 1.

Ample evidence will be found in the experiments we have already quoted, and in those we have still to describe, to show that the course of complete purification of a polluted water by bacterial fermentation proceeds in two distinct and progressive stages, as indicated by the above experiments.[*]

PART III.

Conditions under which Nitrogen does, and does not, appear amongst the Products of Aerobic Fermentation.

It will have been noticed that in all the experiments so far summarised the evidence which they afford as regards the question whether free nitrogen is formed during fermentation under continual aerobic conditions is entirely negative. The determinations of the dissolved nitrogen before and after fermentation in each polluted water are similar; the combined total nitrogen determinations before and after fermentation are likewise nearly equal one to the other.

Similar results will also be found to obtain with all the experiments with polluted waters yet to be described, except in those in which the polluting matters were in excess of the dissolved oxygen, and in which anaerobic fermentation set in after the absorption of the dissolved oxygen; under this condition free nitrogen is evolved.[†]

On reference, however, to Frankland's filtration experiments quoted on p. 4, it will be found that the total combined nitrogen in the effluents in all cases show a considerable loss as compared with the original samples of sewage. There can be no doubt that continual aerobic conditions obtained during fermentation in these experiments; similarly in the experiments with the samples of septic tank liquor, which will be summarised later on, Table 29, p. 73. Two series of experiments were made with this sample. In one, portions were mixed with water and fermented under continual aerobic conditions, while in the other, portions were slowly passed through a fine percolating gravel filter in the undiluted condition. The results show no loss of nitrogen in the former series, but a considerable loss in the latter series.

It is difficult to see any other explanation for the loss of nitrogen in these filtration experiments except to conclude from the fact that filters afford much more favourable conditions for oxidation than do dilute solutions of polluting matters excluded from contact with the air, and that, in consequence, the oxidation of the organic matters passing through them is more complete, free nitrogen being found in addition to ammonia, which is the only inorganic nitrogen product formed under less active conditions of fermentation; hence the loss of nitrogen in the one case and not in the other.[‡]

It may also be pointed out that the foregoing experiments, and those which have yet to be described, all go to show without exception that a preliminary stage of anaerobic fermentation is not, as some authorities hold, necessary for the rapid aerobic fermentation of organic substances, including sewage matters, by water bacteria.

PART IV.

The Quantities of Oxygen absorbed and of Products formed on the Completion of each Stage of Aerobic Fermentation constant for similar Volumes of the same Polluted Water.

We have already pointed out in reference to the foregoing experiments that they afford some evidence to show that the quantities of oxygen absorbed and of inorganic products formed, on the completion of the first stage of fermentation, are practically constant for similar volumes of the same polluted water.

The following table of experiments with an average sample of portions of sewage hourly collected from 6 a.m. to 6 p.m. on June 21st, 1893, at the Richmond Main Drainage

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[*] It has been kindly pointed out to us by Dr. Gilbert J. Fowler that this conclusion has been confirmed by careful work by Boulanger and Massol, *Annales de l'Institute Pasteur*, XVII. and XVIII., Lille Report, pp. 120, *et seq.*, 1905, and by recent observations of his own in Calcutta.

[†] See Tables 10 and 12, pp. 28 and 29.

[‡] It is possible that the loss may have been partially due to adsorption of nitrogenous matters from the sewage by the filtering material, but not, we believe, to any great extent, since the adsorbed matter would itself quickly ferment, and give rise to the formation of ammonia and of other products which would raise the nitrogen content of the effluent. It might be contended that the adsorbed matter when fermenting would cause a reducton of nitrates and nitrites to an extent sufficient to account for the total loss of nitrogen, but we believe that this could only happen in the case of filters composed of coarse material, and certainly not with the fine sand filter employed by Frankland for the experiments quoted on page 10.

In a paper by Dr. Fowler and Percy Gaunt, recently published in the *Jour. Soc. Chem., Ind.*, July, 1907, it is shown that a loss of ammonia would be caused in such experiments as those above by adsorption to some extent of *ammonium compouuds* by the filtering material.

Works confirm this conclusion, and also afford evidence that it may be extended to include the second stage of change. The sample was passed through an ordinary paper filter, and a series of mixtures made with it and with tap water in the proportion of 1 to 9, 39 and 79 volumes, respectively :—

TABLE 10.—Experiments showing that the Quantities of Oxygen absorbed, and of Products formed, on completion of each stage of Aerobic Fermentation in Polluted Waters, are constant for similar volumes of the same Polluted Water. The Volumes of Gases, and the Weights of Nitrogen as Ammonia and as Nitric Acid, are given in a Series of Mixtures of Sewage and Tap Water, before and after Fermentation. The Gases are expressed in c.c., measured at 0°C., and 760 mm. bar., the Nitrogen as Ammonia and Nitric Acid as Parts by Weight, per 1000 c.c. of Mixture. (*Adeney.*)

Strength of Mixture.	Duration of Experiment.	Carbon dioxide	Oxygen.	Nitrogen.	Nitrogen as		Remarks.
					Ammonia	Nitrates.	
1 in 10	When freshly made	23·35	6·42	13·41	·0045	·0001	
	After keeping 31 days	29·44†	0·00	14·83‡	·0047	0·0	Very offensive.
1 in 20	When freshly made	14·21	6·44	13·41	·00225	·0001	
	After keeping 32 days	19·78	0·18	13·49	·0025	0·0	Inodorous, clear.
1 in 40*	When freshly made	9·64	6·46	13·41	·001125	·0001	
	After keeping 32 days	12·45	3·16	13·49	·00115	·0001	Clear and inodorous.
1 in 80	When freshly made	7·36	6·46	13·41	·00056	·0001	
	After keeping 69 days	9·17	2·12	13·34	0·0	·0008	Ditto.

* The remainder of this mixture was, immediately after examination, re-aerated, analysed, and set aside to ferment, and re-examined with the following results :—

1 in 40	When re-aerated	11·31	5·78	12·96	·00115	·0001	
	After keeping 37 days	11·99	1·44	12·99	0·0	·0017	Ditto.

† This volume includes traces of SH_2.
‡ This volume included N_2, CH_4, and H_2.

The relationships which exist between the volume of oxygen absorbed, and of products formed, and the relation also between them both, and the quantities of sewage matters originally present in the mixtures, are more clearly seen when the results are multiplied, so as to render each series comparable to one another and to the original filtered sewage. Thus—

TABLE 11.—Showing the Relationships between the Results recorded in the preceding Table.

Solution.	Multiplier.	1 CO$_2$	2 N as NH$_3$	3 N as N$_2$O$_5$	4 O in c.cs. =N$_2$O$_5$	5 Sum of 1 and 4	6 Vol. of O$_2$ absorbed
1/10 - - - - - - - -	10	+ 61	+0·002	0·0	0·0	61	64
1/20 - - - - - - - -	20	+111	+0·005	0·0	0·0	111	123
1/40 (1st stage) - - - - -	40	+112	+0·001	0·0	0·0	112	132
1/40 (2nd stage) - - - - -	40	+ 27	−0·046	+0·064	204	231	174
1/80 - - - - - - - -	80	+145	−0·045	+0·056	179	324	347

The volume of oxygen given in column 4 as equivalent to the weights of N_2O_5 in the preceding column have been added for convenience of comparison ; they have been calculated from the equation :—

$$2NH^3+4O_2=N_2O_5+3H_2O.$$

This equation gives 3·19 c.cs. oxygen at N.T.P. as the volume required to oxidise 0·001 grammes nitrogen as NH_3 to N_2O_5.

Column 5 gives the sum of the volumes of carbon dioxide actually formed, and of oxygen theoretically equivalent to the nitric acid formed. It has also been added for comparison with the volumes of oxygen actually consumed.

In the experiments with the mixtures 1/20 and 1/40, the first stage of fermentation was evidently complete, and the volume of carbon dioxide formed, and of oxygen absorbed, were practically proportional to the quantities of sewage originally present in them, for the volumes of the two gases were, respectively, proportional to 111 c.c. and 123 c.c. in the first case, and to 112 c.c. and 132 c.c., in the second case, per litre of filtered sewage.

A similar relationship is also indicated between the volumes of oxygen absorbed and of carbon dioxide formed (and also of the inorganic nitrogen products), on the completion of the second stage of fermentation. Thus in the second experiment with the mixture 1/40, it will be found that the volumes of carbon dioxide formed, and of oxygen absorbed, when multiplied by the necessary factors, are respectively proportional to 27 c.c. and 174 c.c., per litre of original filtered sewage.

The total volumes of the two gases in the same experiment during the two stages of fermentation are, respectively, proportional to 139 c.c. and 306 c.c. per litre of filtered sewage.

In the next experiment both steps of fermentation had been completed by the time when it was stopped, and the volumes of carbon dioxide formed, and of oxygen absorbed were, respectively, proportional to 145 c.c., and 347 c.c., per litre of unfiltered sewage.

These two sets of numbers may be accepted as in close agreement, when it is remembered that the experimental errors are largely exaggerated by the multiplication necessary to render them comparable.

We may quote one more series of experiments with mixtures of different strengths of sewage and tap water, in confirmation of the above conclusions.

The sewage which was employed for this series of experiments was collected from the main sewer at Monkstown, a residential suburb of Dublin. The sample was passed through an ordinary paper filter to separate the suspended matters, and mixtures were made from the filtrate and tap water in the proportion of 1 volume of the former to 9, 19, 29, 39, 49, 59, 69, 79, 89, and 99 volumes of the latter.

In the first of the two following tables the experimental data are given, in the second, the values obtained by multiplying the results for each mixture by the necessary factor to make them comparable with the original filtered sewage.

Table 12.—Experiments showing that the Quantities of Oxygen absorbed, and of Products formed, on Completion of Each Stage of Aerobic Fermentation in Polluted Waters are constant for Similar Volumes of the same Polluted Water. The Volumes of Dissolved Gases, and the Weights of Nitrogen as Ammonia and as Nitric Acid, are given in a Series of Mixtures of Filtered Sewage and Tap-water, before and after Fermentation. The Gases are expressed in c.c., measured at 0°C., and 760 mm. bar.; the Nitrogen as Ammonia and Nitric Acid as Parts by Weight, per 1,000 c.c. of mixture. (*Adeney.*)

Strength of Mixture.	Duration of Experiment.	Carbon dioxide.	Oxygen.	Nitrogen.	Nitrogen as		Remarks.
					Ammonia	Nitrates.	
1 in 100	When freshly made -	4·32	8·03	15·96	·00062	·00010	
	After keeping 57 days	6·70	2·54	15·60	0	·001	Clear and inodorous.
1 in 90	When freshly made -	4·43	8·02	15·96	·00067	·0001	
	After keeping 70 days	7·15	1·68	15·61	0	·0012	Clear and inodorous.
1 in 80	When freshly made -	4·51	8·02	15·90	·00077	·0001	
	After keeping 71 days	7·64	0·77	15·60	trace	·0012	Clear and inodorous.
1 in 70	When freshly made -	4·66	8·00	15·96	·00086	·0001	
	After keeping 71 days	7·94	0·62	15·60	·00012	·0012	Clear and inodorous.
1 in 60	When freshly made -	4·81	8·00	15·97	·001	·0001	
	After keeping 72 days	9·18	0·48	15·68	·0008	·0008	Clear and inodorous.
1 in 50	When freshly made -	5·09	7·98	15·97	·0012	·0001	
	After keeping 72 days	10·23	0·00	15·55	·0012	·0006	Clear and inodorous.
1 in 40	When freshly made -	5·46	7·96	15·99	·0015	·0001	Stale inoffensive odour.
	After keeping 72 days	11·55	0·00	15·51	·0019	·0004	
1 in 30	When freshly made -	6·08	7·92	15·98	·002	·0001	
	After keeping 73 days	13·11	0·00	15·79	·0032	0·0000	Offensive odour.
1 in 20	When freshly made -	7·31	7·85	15·99	·003	·0001	
	After keeping 78 days	18·56*	0·00	15·80	·005	0·0000	Very offensive odour.
1 in 10	When freshly made	11·03	7·63	16·07	·006	·0001	
	After keeping 78 days	26·40*	0·0	20·09†	·0068	0·0000	Very offensive odour.
Tap-water	When fresh - -	3·58	8·07	15·95	0·000	·0001	
	After keeping 78 days	3·45	8·00	15·82	0·000	·0001	Inodorous.

Note.—Nitrous acid was not detected in any of the mixtures after fermentation.

* Each of these volumes include small volumes of SH_2.

† This volume includes CH_4 and H_2. They were not determined owing to an accident during analysis.

TABLE 13.—Showing the Relationships between the Results recorded in the preceding Table.

Solution.	Multiplier.	1 CO_2	2 N as NH_3	3 N as N_2O_5	4 O in c.cs. equivalent to N_2O_5	5 Sum of 1 and 4.	6 Volume of O Absorbed.
1/100	100	+238	—0·062	+0·09	287	525	549
1/90	90	+245	—0·060	+0·099	316	561	571
1/80	80	+254	—0·062	+0·088	281	535	580
1/70	70	+230	—0·052	+0·077	245	475	517
1/60	60	+262	—0·012	+0·042	134	396	451
1/50	50	+257	—0·0	+0·025	80	337	399
1/40	40	+244	+0·016	+0·012	38	282	318
1/30	30	+211	+0·036	0·0	0	211	238
1/20	20	+225	+0·04	0·0	0	225	157
1/10	10	+154	+0·008	0·0	0	154	76

It is unnecessary to discuss in detail the results in these last two tables, as it will be found on examination that they fully confirm the conclusions to be drawn from those recorded in all the preceding experiments.

On comparing the fermentative changes which occurred in the above two series of mixtures with those which were observed in the experiments with the solutions of simple organic substances, it is evident that the course and nature of the changes in each case were similar in character, and so it will be found with the experiments which we have yet to describe. No experimental evidence has in fact been found to show that the course of change varies to any appreciable extent from that illustrated by the foregoing experiments, under similar conditions of oxygen supply. *We may hence conclude that the law above enunciated, viz., the quantities of oxygen absorbed, and of products formed, on the completion of each stage of aerobic fermentation is constant for similar volumes of the same polluted water, is applicable to all polluted waters undergoing purification by bacterial fermentation provided that the dissolved oxygen is in excess of the fermenting matters.*

PART V.

THE COURSE AND NATURE OF THE CHANGES WHICH OCCUR DURING THE SECOND STAGE OF FERMENTATION IN POLLUTED WATERS.

From the experiments which we have so far discussed we have gained a knowledge of the course of chemical changes which proceed in polluted waters during fermentation under continual aerobic conditions. We have learned that they proceed in two distinct and successive stages; and we have considered in detail the precise nature of the changes which occur during the first stage. We have now to make a similar enquiry into the nature of the changes which take place during the second stage.

We already know, from the experiments with distilled water polluted by known quantities of Rochelle salt and asparagin, and also from the experiments with the sample of sewage from the Richmond Works, Table 10, p. 28, that the possible inorganic products of a second stage fermentation are carbon dioxide, nitrites and nitrates.

We have first to enquire into the nature of the organic substances resulting from fermentative change in the experiments referred to. For reasons which have already been given, p. 23, they must be regarded as the waste or bye-products which result from the synthesis of constructive material required for new carbon-oxidising organisms.

They are similar, as we shall see, in colour and in fermentative properties to the coloured organic substances of peat and of the humus of cultivated soils. They are also similar to them in the relative proportions of carbon and nitrogen which they contain.

One of the authors (Adeney)* has found that, on allowing sewage slowly to percolate through a pumice filter, effluents were obtained which were decidedly coloured with a brown tint, that could not be distinguished from that of upland surface waters. On separating the colouring matters from the waters, they were found on analysis to give the proportion of carbon to nitrogen as 7·1 : 1.

On keeping the effluents it was found that the ammonia which they contained was rapidly fermented to nitric acid.

Since the products of fermentation of these bodies are carbon dioxide and nitric acid, we may term them nitrifiable organic substances, to distinguish them from unfermented organic substances.

1. *Changes which occur in Effluents from Percolating Filter Beds.*

For the purpose of studying the fermentative changes which these coloured substances undergo, and the influence which they exert on the course of oxidation of ammonium compounds, a number of experiments have been made with samples which were derived both from sewage and from peat.

The following were made with mixtures of tap water and with an average sample of portions of effluent hourly collected from 6 a.m. to 6 p.m., on June 21, 1893, from a gravel filter bed at the Richmond Main Drainage Works. The sample was of a yellowish brown tint. It was passed through a paper filter previous to the preparation of the mixtures :—

TABLE 14.—Experiments showing the Course and Nature of the Changes which occur during the Second Stage of Fermentation in Polluted Waters. The Volumes of Dissolved Gases, and the Weights of Nitrogen as Ammonia and as Nitric Acid are given in a Series of Mixtures of a Sewage Effluent from a Gravel Filter Bed, with Tap Water, before and after Fermentation. The Gases are expressed in c.c., measured at 0°C., and 760 mm. bar.; the Nitrogen as Ammonia and Nitric Acid as Parts by Weight, per 1,000 c.c. of mixture.—(*Adeney.*)

Strength of Mixture.	Duration of Experiment.	Carbon-di-oxide.	Oxygen.	Nitrogen.	Nitrogen as— Ammonia.	Nitrites.	Nitrates.
1 in 2	When freshly made - -	77·50	6·38	13·58	·0085	·0018	·003
	After keeping 24 days - -	83·85	0·00	13·70	·0075	·0016	·0045
1 in 4	When freshly made - -	41·29	6·43	13·58	·00425	·0009	·00155
	After keeping 25 days - -	44·00	0·00	13·54	·003	·00003	·0028
1 in 8	When freshly made - -	23·18	6·45	13·58	·00213	·00045	·000825
	After keeping 26 days - -	24·80	0·00	13·43	·0005	·0000	·0028
1 in 16	When freshly made - -	14·12	6·46	13·58	·0011	·00023	·0004
	After keeping 30 days - -	15·11	3·41	13·54	·00025	·000	·0015

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* *Loc. cit.*, p. 594.

It may be taken for granted, from the fact that nitrification had already been well established in this sample of sewage effluent, and from the general character of the results obtained, that the first stage of fermentation had been completed during the process of filtration to which it had been subjected.

On multiplying each series of results by the necessary factors in order to make them comparable to the undiluted sample, we get the following proportional values :—

TABLE 15.—Showing the Relationships between the Results recorded in the preceding Table.

Solution.	Multiplier.	1 CO_2.	2* N as N_2O_3 oxidised to N_2O_5.	3 $O_2{=}N_2O_3$ oxidised.	4† N as N_2O_5 from NH_3.	5 $O_2{=}NH_3$ oxidised.	6 Sum of 1, 3, and 5.	7 Vol. of O_2 absorbed.
1/2	2	12·7	0·0004	0·32	0·0026	8·29	21·31	12·8
1/4	4	10·8	0·00348	2·78	0·0015	4·79	18·37	25·7
1/8	8	13·0	0·0036	2·86	0·0122	38·92	54·80	51·0
1/16	16	15·8	0·0036	2·88	0·0124	39·56	58·24	48·8

It will be observed that in each of these experiments a decided volume of carbon dioxide was formed together with the nitric acid, and that the volume of oxygen actually absorbed in each, with the exception of the experiment with the mixture 1/4, was much less than that theoretically equivalent to the total inorganic products.

The result found for the mixture 1/4 appears to be exceptional when compared with those recorded for the other mixtures.

Thus, relatively less carbon dioxide was formed in it; and the total inorganic nitrogen found after fermentation was decidedly less than that present before it, the quantities being 0·00583 and 0·0067 parts per 1,000 respectively.

It should be noted that although the dissolved oxygen was completely absorbed, the fermentation was not complete in the mixture, inasmuch as the polluting matters were in excess of oxygen. The observed difference in the results are to be ascribed to intermediate compounds formed between the polluting matters and the dissolved oxygen during intermediate steps of the fermentation. More distinct evidence of the formation of such intermediate compounds will be met with when the experiments with coloured substances derived from peat are considered.

2. *Changes which occur in Distilled Water Polluted by Humus and Ammonium Compounds.*

Experiments have also been made with a sample of humus†† which had been formed by the fermentation of the organic matters in some sewage sludge which had been allowed to ferment for some time under what were practically aerobic conditions. The sludge had been obtained from a sewage purification works, in which the coarser portions of the solid matters in suspension in the sewage were first separated by mechanical subsidence, and in which the sewage was then mixed with a little manganate of soda. The peroxide, which separated out, was allowed to subside, together with the matters remaining in suspension

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The numbers in this column have been calculated on the assumption that the N as N_2O_3, shown to have been absorbed during fermentation, was completely oxidised to N_2O_5; and the figures in the next column have been calculated on the assumption that the oxidation of the N_2O_3 took place according to the equation $N_2O_3 + O_2 = N_2O_5$. This gives 0·8 c.cs. oxygen required to oxidise 0·001 grammes N as N_2O_3 to N_2O_5.

† The numbers in this column give the N_2O_5 less the loss of N_2O_3 during fermentation, and it is assumed that these quantities were derived from ammonia. The numbers in the next column have been calculated on this assumption, as already explained, Table 11. These four columns have been added simply for the purpose of approximate comparison. It will be observed that the total N as NH_3 and N_2O_3 lost in the case of each solution, except solution 1/4, is nearly equal in quantity to the N as N_2O_5 formed.

†† See page 53.

in the sewage, to the bottom of the tank in which the operation was conducted. It was finally drawn off from the tank in form of brown mud. This was drained on a gravel bed, and, when of sufficient consistence, it was made up into a large heap and allowed to ferment in a covered shed. During the fermentation the peroxide of manganese was reduced to manganous oxide and converted into manganous carbonate; the liberated oxygen was taken up by the organisms at work for the oxidation of the fermenting organic matters.*

In three months' time the interior portion of the mud had assumed a grey colour. On examination, air dried samples were found to contain no unfermented organic matter, but 8·35 per cent. of humus-like organic matter. This on separation from the mineral matter was brownish-black in colour; it was insoluble in hydrochloric acid, but completely soluble in a solution of sodium carbonate. The solution obtained was of a deep brown colour. On analysis of this humus the ratio of organic carbon to nitrogen in it was found to be 6·84 : 1. It was therefore similar in these particulars to the organic matters in the coloured matters of peat.† A solution of the humus was prepared by dissolving a known weight in distilled water and a little sodium carbonate. A few drops of sediment from one of the experiments with the peat extract, next to be described, were added for the purpose of seeding, together with the necessary mineral salts. The experiments with this solution are recorded in the following tables. On examination the results will be found to show that the influence of the humus on the course of oxidation of the ammonium compounds is of a similar character to that of the coloured substances of the sample of sewage effluent just considered.

TABLE 16.—Experiment showing the Course and Nature of the Changes which occur during the Second Stage of Fermentation in Polluted Waters. Experiments with Humus obtained by the Fermentation of wet solid Sewage Matters in the presence of Hydrated Manganese Peroxide. (*Adeney.*)

Solution H contained 0·0465 grams. organic carbon,
0·0068 „ „ Nitrogen,
0·1 „ Na_2HPO_4,
0·1 „ KCl,
a small quantity of $NaHCO_3$, } per litre.

(The gases are expressed in c.c., measured at 0°C., and 760 mm. bar., the other constituents as parts by weight per litre of water.)

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2.	O_2.	N_2.	N as NH_3.	N as N_2O_3.	N as N_2O_5.	Remarks.
1	Feb. 24, 1896	Solution H, aerated	16·73	7·52	15·30	·0002	0	0	Deep brown colour.
	Mar. 17, „	Same after fermentation.	17·80	5·29	15·35	·0002	0	·0002	Ditto.
1a	July 20, „	Another bottled portion after fermentation.	19·84	2·09	15·26	0	0	·0006	Ditto.
2	Feb. 24, „	Solution H+AmCl =H_1.	16·73	7·52	15·30	·004	0	0	
	Mar. 2, „	Same after fermentation.	17·23	6·52	15·2	·004	0	0 ?	
2a	„ 30, „	Another bottled portion after fermentation.	18·19	4·81	15·33	·004	0	·0002 ?	
3	„ 16, „	Solution H, diluted with distilled water, 1 : 9.	7·08	7·66	15·2	·0005	0	·0008	Faintly but distinctly coloured greenish yellow.
	„ 24, „	Same after fermentation.	8·97	3·51	15·0	0	0	·001	Ditto.
3a	„ 25, „	Another bottled portion.	8·51	3·66	15·08	0	0	·001	Ditto.

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* Adeney, Trans. Royal Dublin Society, p. 272, 1897.

† Rivers Pollution Commission, 6th Report, pp. 6–10.

TABLE No. 16—*continued.*

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5	Remarks.
4	March 31, 1896	Remaining solution from Exp. 1 and 1a + more solution (H^1) of Humus + AmCl (prepared Feb. 26); whole diluted with equal bulk of water = H_2.	24·09	7·77	15·48	·0024	0	·0004	Strongly coloured brown.
	July 21, „	Same after fermentation.	26·49	0	15·34	·0001	·00112	·00078	Ditto.
4a	„ 23, „	Another bottled portion after fermentation.	26·22	0	15·39	·00005	·00144	·00091	Ditto.
5	April 4, „	Solution H_2 + AmCl, diluted with distilled water, 1 : 6.	7·78	7·59	15·30	·0016	0	·0002	Faintly but distinctly coloured yellowish brown.
	July 25, „	Same after fermentation.	7·72	1·16	15·13	0	0	·0018	Ditto.
5a	Jan. 5, 1897	Another bottled portion after fermentation.	7·65	0·98	15·16	0	0	·00195	Ditto.

3. *Changes which occur in Waters Polluted by Peaty Matters and Ammonium Compounds.*

The next experiments were made with an extract of fresh peat that was collected from a bog situated on one of the Wicklow mountains, and far removed from any source of contamination with animal matters. The extract was prepared by boiling the peat in tap water containing a little sodium hydrate. The extract was filtered into a large glass-stoppered jar, which it filled to about two-thirds of its capacity. It was allowed to ferment for nearly six months, the stopper of the jar being taken off from time to time to renew the air. It was then thoroughly mixed with about five times its bulk of tap water and allowed to settle until the following day, when about 6 litres were decanted off, and the experiments commenced which are recorded in the two following tables :—

TABLE 17.—Experiments showing the Course and Nature of the Changes which occur during the Second Stage of Fermentation in Peaty Waters (Adeney).

Experiments with a Solution of Peat. Commenced 9th March, 1894.

Solution P contained 0·0033 grammes nitrogen as ammonia } per litre.
0·1336 „ organic carbon
0·0079 „ organic nitrogen

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	Carbon dioxide.	Oxygen.	Nitrogen.	Nitrogen as		
						Ammonia.	Nitrites.	Nitrates.
1	March 9, 1894	Solution P - - - -	114·65	7·14	14·27	0·0033	0·0	0·0
	May 11, „	Same after fermentation*	136·03	0·0	14·70	0·0044	0·0	0·0
		Results of fermentation -	+21·38	−7·14	—	+0·0011	—	—
2	„ 18, „	Remainder of preceding solution diluted with twice its bulk of distilled water aerated and exposed to the air for a week, then aerated again and bottled = P/3† -	41·46	7·44	14·96	0·0012	0·0	0·0

* Very offensive odour. † Free from offensive odour.

TABLE 17—*continued.*

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	Carbon dioxide.	Oxygen.	Nitrogen.	Nitrogen as		
						Ammonia.	Nitrites.	Nitrates.
	July 27, 1894	P/3 after fermentation -	49·96	0·0	15·08	0·00048	0·0	0·0004
		Results of fermentation	+7·50	−7·44	—	−0·00072	—	+0·0004
3	„ 27, „	Remainder of preceding solution aerated - -	44·91	6·45	12·86	0·00046	0·0	0·0004
	Nov. 15, „	Same after fermentation	49·24	0·0	13·09	0·00014	0.0	0·0002
		Results of fermentation	+4·33	−6·45	—	−0·00032	—	−0 0002
4	„ 16, „	Remainder of preceding solution aerated - -	48 06	7·24	14·86	0·00014	0·0	0·0002
	Jan. 29, 1895	Same after fermentation	50·96	2.75	14·67	0·0	0·0	0·0003
		Results of fermentation	+2·90	−4·49	—	−0·00014	—	+0·0001
5	May 18, 1894	A portion of the solution P/3 from experiment No. 2, diluted with twice its bulk of distilled water=P/9 - - -	14·70	7·46	14·77	0·0004	0·0	0·0
	June 12, „	Same after fermentation I.	16·67	3·95	14·67	0·0	0·0	0·00035
	July 20, „	Another bottle of same after fermentation II.	19·02	1·77	14·74	trace	0·0	0·00035
	„ 23, „	Another bottle of same after fermentation III.	19·21	1·66	14·69	0·0	0·0	0 00035
		Results of fermentation						
		„ „ I.	+1·97	−3·51	—	−0·0004	—	+0·00035
		„ „ II.	+4·32	−5·69	—	−0·0004	—	+0·00035
		„ „ III.	+4·51	−5·80	—	−0·0004	—	+0·00035
6	„ 21, „	Remainder of solution II. aerated - - -	17·75	6·42	13·22	trace	0·0	0·00035
	Nov. 22, „	Same after fermentation IV. - - - -	19·15	3·91	13·27	0·0	0 0	0·0007
		Results of fermentation IV. - - - -	+1·40	−2·51	—	—	—	+0·00035
	Jan. 30, 1895	Another of same after fermentation V. - -	19·25	3·89	13·11	0·0	0·0	0·0007
		Results of fermentation V. - - - -	+1·50	−2·53	—	0·0	0·0	+0 00035

TABLE 18.—Experiments showing the Course and Nature of the Changes which occur during the Second Stage of Fermentation in Peaty Waters. Experiments with solution of Peat and Ammonium Chloride. Commenced 9th March 1894. (*Adeney.*)

Solution PA (=P/2+AmCl.) contained	0·1 grammes	ammonium chloride	per litre.
„ „ „	0·069 „	organic carbon	
„ „ „	0·004 „	organic nitrogen	

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	Carbon dioxide.	Oxygen.	Nitrogen.	Nitrogen as		
						Ammonia.	Nitrites.	Nitrates.
1	Mar. 9, 1894	Solution PA=P/2+Am Cl. - -	59·29	7·4	15·14	0·1	0·0	0·0001
	May 12, „	Same after fermentation	72·26	0·0	15·17	0·1	0·0	0·0
		Results of fermentation	+12·97	−7·4	—	—	—	−0·0001
2	„ 14, „	Remainder of PA after fermentation diluted with twice its bulk of of distilled water and aerated =PA/3 -	23·80	7·26	14·54	0·032	0·0	0·0
	June 15, „	Same after fermentation	25·55	0·0	14·55	0·028	0·00225	0·0
		Results of fermentation	2·75	−7·26	—	−0·004	+0·00225	—

TABLE 18—*continued.*

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	Carbon dioxide.	Oxygen	Nitrogen.	Nitrogen as		
						Ammonia.	Nitrites.	Nitrates.
3	June 18, 1894	Remainder of PA/3 after fermentation aerated -	22·74	6·8	13·58	0·027	0·0024	0·0004
	„ 28, „	Same after fermentation	22·18	0·0	13·60	0·023	0·0024	0·0037
		Results of fermentation	−0·56	−6·8	—	−0·004	—	+0·0033
4	„ 28, „	Remainder from preceding aerated - -	15·51	6·5	12·99	0·002	0·0021	0·004
	July 17, „	Same after fermentation	16·58	0·15	13·09	0·0198	0·00048	0·0065
		Results of fermentation	+1·07	−6·35	—	−0·0022	−0·0016	+0·0025
5	„ 21, „	Remainder from preceding aerated - -	*5·82	6·55	13·19	0·019	0·0006	0·0070
	Jan. 28, 1895	Same after fermentation	6·58	0·0	13·29	0·018	0·0032	0·0088
		Results of fermentation	+0·77	−6·55	—	−0·001	+0·0026	+0·0018
1a	Mar. 9, 1894	Solution PA diluted with tap water in the proportion of 1 to 9 = PA/10 = P/20 + Am Cl. - - -	9·46	7·5	15·54	0·01	0·0	0·0001
	May 14, „	Same after fermentation	21·52	0·0	15·55	0·007	0·0033	0·0
		Results of fermentation	+12·06	−7·5	—	−0·003	+0·0033	—
2a	„ 16, „	Remainder of PA/10 aerated - - -	18·99	7·24	14·58	0·007	0·0033	0·0
	June 21, „	Same after fermentation	19·96	0·0	14·48	0·0035	0·006	0·0004
		Results of fermentation	+0·97	−7·24	—	0·0035	+0·0027	+0·0004
3a	„ 22, „	Remainder from preceding aerated - -	14·83	7·2	14·15	0·0024	† 0·0009	† 0·0067
	Jan. 31, 1895	Same after fermentation	18·39	0·0	13·96	0·00005	0·004	0·00815
		Results of fermentation	+3·56	−7·2	—	−0·00239	+0·0031	+0·00145
1b	Mar. 9, 1894	Solution PA diluted with tap-water in the proportion of 1 to 19 = PA/20 = P/40 + Am Cl. - - - -	6·69	7·5	15·54	0·005	0·0	0·0001
	May 15, „	Same after fermentation	15·02	0·0	15·55	0·0026	0·0021	0·0004
		Results of fermentation	+8·33	−7·5	—	−0·0024	+0·0021	+0·0003
2b	„ 17, „	Remainder of PA/20 aerated - - -	11·82	7·2	14·37	0·0018	0·0021	0·0004
	June 20, „	Same after fermentation	11·06	0·0	14·28	0·0001	0·00018	0·00332
		Results of fermentation	−0·76	−7·2	—	−0·0017	−0·00192	+0·00292

Referring to the first of the two foregoing tables, we find from the first experiment that the organic matters in solution had not undergone a complete first stage fermentation. The remaining portions of the solution P were in consequence diluted with twice their bulk of distilled water and exposed to the air for a week to allow of the completion of this stage of fermentation. We may take it that this had the desired effect, from the fact that nitrification had commenced in Experiment 2. The points most markedly exhibited by Experiments 2 and 3 are a formation of carbon dioxide and a loss of oxygen and ammonia. As regards the indications of nitrification, they are decided in the former experiment, but the nitric acid formed during it was only equivalent to about half the quantity of ammonia absorbed, while in the latter experiment no nitric acid appears to have been formed, although a very decided quantity of ammonia was absorbed. It appears from these experiments that a fermentation of small quantities of ammonia in the presence of considerable quantities of peaty colouring matters may be accompanied by intermediate changes in which the ammonia is absorbed and carbon dioxide is formed, while oxygen is consumed in relatively large volumes, but from which little or no nitric (no nitrous) acid results.

Remarks.—* The very rapid reduction of carbonic acid here shown, during the time the liquid was exposed to the air, was confirmed by a duplicate analysis (5·81). The loss may have occurred by diffusion, but I have not observed so great a loss in any other of my experiments under similar conditions.

† These results show that an extremely rapid oxidation of nitrous to nitric acid occurred when the liquid was exposed to the air between the 21st and 22nd June. The figures were confirmed by duplicate analyses.

In Experiment 4, the nitric acid formed is about equivalent to the ammonia absorbed. It is important, however, to note that this last product is the least marked result of the fermentation, the volume of carbon dioxide formed and of oxygen consumed being relatively both very much larger in quantity.

Experiments 5 and 6 were made with a diluted portion of solution P/3 prepared for Experiment 2, and the former of these two experiments was commenced on the same day as the last mentioned. It is possible, therefore, to compare the results obtained with the solutions, P/3 and P/9, which differed only in degree of dilution.

An intermediate step of fermentation of the latter solution is shown by the analysis of the portion I. The ammonia was completely fixed, and a quantity of nitric acid practically equivalent to the ammonia lost, and some carbon dioxide, were formed.

The results obtained with the other portions of the same solution, bottles II. and III., after keeping them for a further period of about six weeks, were a further formation of carbon dioxide and a consumption of oxgyen, *but no additional formation of nitric acid.* On re-aerating, however, a portion of the solution in bottle II. remaining from the experiment, and keeping portions of it for further periods of time, one of four and another of six months, the formation of carbon dioxide and the absorption of oxygen was accompanied by a formation of a decided quantity of nitric acid.

The products formed during this last experiment must have been derived entirely from the peaty matters present in solution.

The influence of dilution on the fermentative changes is clearly seen when the products formed during the different steps of fermentation represented by Experiments 2, 3, and 4 with less dilute solutions, and by Experiments 5 (bottle III.) and 6 (bottle V.), are respectively added together, thus—

——	——	O_2.	CO_2.	N as NH_3.	N as N_2O_5.
Solution P/3	Exp. 2, 3, and 4	– 18·38	+ 14·73	– ·0012	+ ·0003
Solution P/9	Exp. 5 (III.) and 6 (V.)	– 8·33	+ 6·01	– ·0004	+ ·0007

The experiments recorded in the second of the foregoing tables were made with another portion of the same solution of peat, but it was mixed with a relatively large quantity of ammonium chloride. The results of the experiments prove that peaty matters when mixed with ammonium compounds readily undergo fermentation, but that intermediate combinations may occur between them during the progress of the fermentation.

Thus from Experiment 2 we find 7·26 c.c. oxygen, and ·004 grms. of ammoniacal nitrogen were taken up, and only ·00225 grms. of nitrous nitrogen were formed; the volume of oxygen theoretically equivalent to this quantity of nitrous nitrogen being 5·38 c.c., a volume much less than that consumed; 2·75 c.c. carbon dioxide were also formed.

From Experiment 3 we find the quantities of oxygen and ammoniacal nitrogen taken up were respectively 6·8 c.c. and ·004 grm., and that of nitric nitrogen formed ·0033 grm.; *but no carbon dioxide was formed, on the contrary,* 0·56 *c.c. was fixed.* The volume of oxygen theoretically equivalent to the nitric nitrogen formed during this step of the fermentation is 10·53 c.c., a volume this time much in excess of that actually consumed. It thus appears from this last observation that interchanges between the peaty matters, carbon dioxide, ammonia and oxygen of a different character to those which occurred in the preceding step, took place.

Experiment 4 demonstrates another phase of interchange; thus the quantities of oxygen and of ammoniacal and nitrous nitrogen taken up were, respectively, 6·35 c.c., ·0022 grm., and ·0016 grm., while the quantities of carbon dioxide and nitric nitrogen formed were 1·07 c.c. and ·0025 grm. respectively. The volume of oxygen theoretically equivalent to this last-mentioned quantity of nitric nitrogen, assuming that part of it was derived from the nitrous nitrogen taken up, and that the rest was derived from ammonia, is 4·15 c.c., a volume again less than that consumed.

A further phase of interchange is indicated by the results with Experiment 5. The quantities of oxygen and ammoniacal nitrogen absorbed, and of carbon dioxide, nitrous and nitric nitrogen formed were, respectively, 6·55 c.c., ·001 grm., ·77 c.c., ·0026 grm. and ·0018 grm. The total quantity of nitrous and nitric nitrogen was thus equal to ·0044 grm., a quantity largely in excess of the ammoniacal nitrogen taken up. The total volume of oxygen theoretically equivalent to the nitrous and nitric nitrogen formed, assuming that both were derived from ammonia, is 11·96 c.c. There can, therefore, be no doubt from these results that the nitrogen products formed during this last step of the fermentation were derived from compounds resulting from the interchanges which evidently occurred between the peaty matters, ammonia and oxygen during the earlier steps of the fermentation.

If the quantities of the ammoniacal nitrogen which were absorbed, and of the products which were formed during the several steps of fermentation represented by these experiments be respectively added together, it will be found that, although but little carbon dioxide was formed, distinct quantities of the nitrogen originally present in combination with the peaty matters must have suffered oxidation with the ammonia.

The total figures are—

O_2.	CO_2.	N as NH_3.	N as N_2O_3.	N as N_2O_5.
− 26·96	+ 4·59	− ·0112	+ ·00645	+ ·0076.

The total nitrogen oxidised was, as will be seen from these figures, ·01405 grm., a quantity decidedly in excess of the ammoniacal nitrogen absorbed.

4·59 c.c. of carbon dioxide is equivalent to ·0025 grm. carbon, which is but a small fraction of the total quantity of the organic carbon originally present in the solution PA/3, viz., ·023 grm.

On turning to the experiments with PA/10, we find the influence of dilution as markedly shown as in the case of the solutions P/3 and P/9.

Experiment 1a shows that the nitrous nitrogen formed was practically equal to the ammoniacal nitrogen absorbed, and that a considerable volume of carbon dioxide was formed. The oxygen theoretically equivalent to the nitrous nitrogen, 7·85 c.c., is slightly in excess of the volume actually absorbed.

In Experiment 2a the nitrous and nitric nitrogen together practically equalled the ammoniacal nitrogen lost, but this time a very small volume of carbon dioxide was formed. The volume of oxygen theoretically equivalent to the two nitrogen products is 7·70 c.c., a volume also slightly in excess of that actually absorbed, viz., 7·24.

It is interesting to note that the changes which occurred during these experiments practically consisted of a nitrous fermentation, but that when the portion of the solution remaining over from the second experiment was kept in a bottle only partially filled for a single day, the nitrous acid was almost completely fermented to nitric acid.

During the fermentation in the Experiment 3a, the nitrous and nitric nitrogen formed, amounting to ·0036 grm., was considerably in excess of the ammoniacal nitrogen lost, and a decided quantity, 3·56 c.c., of carbon dioxide was produced. The oxygen theoretically equivalent to the two nitrogen products, 8·81 c.c., is decidedly in excess of that actually absorbed, 7·2 c.c.

On summing together the results of these three experiments it will be seen that, by the time of the conclusion of the last, nearly all the fermentable matters, both peat and ammonia, must have been fermented, thus:—

O_2.	CO_2.	N as NH_3.	N as N_2O_3.	N as N_2O_5.
− 21·94	+16·59	− ·0089	+·0091	+·00185

16·59 c.c. CO_2 are equivalent to ·0090 grms. carbon. The organic carbon originally present in the solution PA/10 was ·0089 grm. Again, the total nitrous and nitric nitrogen amounts to ·011 grm., while the total organic and inorganic nitrogen originally present was ·011 grm.

The volume of oxygen theoretically equivalent to the two nitrogen products is equal to 27·66 c.c., which is very much larger than the figures above given for the absorption of oxygen. We may conclude therefore that the oxygen of the peat must have taken part in the fermentative changes.

The results recorded for the more dilute solution PA/20, in the first Experiment 1b, are similar in character to those just considered. The volume of carbon dioxide formed, viz., 8·33 c.c. (equivalent to ·0045 grm. carbon), shows that the peaty matters must have been nearly completely fermented, as the quantity of carbon present before fermentation was only ·0055 grm.

The second Experiment 2b shows the fixation of carbon dioxide and of ammoniacal or nitrous nitrogen, or both. The oxygen theoretically equivalent to the nitric nitrogen, assuming that it was partly derived from the nitrous nitrogen lost, and from ammonia, is 4·73 c.c., while the volume actually consumed was 7·2 c.c.

RELATIONSHIP BETWEEN THE OXYGEN CONSUMED AND THE NITROUS AND NITRIC ACIDS FORMED DURING THE FERMENTATION OF AMMONIA.

The experiments which have just been considered show that when the fermentation of ammonia is carried on in the presence of peaty matters, the latter bodies take part in the fermentation and prevent the true relationship between the oxygen consumed and the ammonia oxidised from being discerned. The same author has published experiments with a solution of ammonium chloride in distilled water to which a little potassium phosphate and sodium carbonate were added, but no organic matter of any kind, with a view of accurately determining this relationship. The solution was seeded with a few drops of sediment from the solution of peat, P/9, remaining from some of the preceding experiments.

In order to be able to compare the results of this experiment with those which would follow a fermentation by similar organisms in the presence of peaty matters, two experiments with portions of the same peat solution were at the same time commenced. To one portion, a known quantity of ammonium chloride was added; to the other a known quantity of potassium nitrite.

The details and results of these experiments are given in the following table.

TABLE 19.—Experiments to determine the relationship between the Oxygen consumed and Nitrous Acid formed during the fermentation of Ammonia.—(Adeney.)

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
1	July 23, 1894	Solution in distilled water containing a known quantity of ammonium chloride, and small quantities of potassium phosphate and sodium carbonate, but no added organic matter, seeded with a few drops of the mixed sediments from the solution of peat left in the bottles II. and III., after the conclusion of Experiment 5, recorded in Table 17.	32·96	6·48	12·94	0·0225	0·0	0·0

TABLE 19—*continued.*

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
	Oct. 25, 1894	Same after fermentation -	32·72	0·0	12·91	0·020	0·00224	0·0
		Results of fermentation -	– 0·24	– 6·48	—	– 0·0025	+ 0·00224	—
1A	,, 26, ,,	Remainder of solution from preceding experiment aerated - - - -	31·52	7·13	14·03	0·019	0·00224	0·0
	Mar. 23, 1895	Same after fermentation, bottle I.	31·25	0·04	13·87	0·016	0·00464	0·0
	,, 26, ,,	,, ,, ,, II.	31·40	0·06	13·95	0·016	0·00472	0·0
		Results of fermentation, I.	– 0·27	– 7·09	—	– 0·003	+ 0·00240	—
		,, ,, ,, II.	– 0·12	– 7·07	—	– 0·003	+ 0·00248	—
2	July 24, 1894	1,000 c.c. of the mixed peat solutions remaining in bottles II. and III., from Experiment 5, Table 17, diluted with 2,000 c.c. distilled water containing a known quantity of ammonium chloride - - - -	11·04	6·72	13·19	0·0045	0·0	0·0001
	Nov. 25, ,,	Same after fermentation	10·92	0·0	13·38	0·0015	0·00016	0·00284
		Results of fermentation -	– 0·12	– 6·72	—	– 0·003	+ 0·00016	+ 0·00274
3	July 25, ,,	1,000 c.c. of the same peat solution mixed with 2,000 c.c. of distilled water containing a known quantity of potassium nitrite - - - -	11·05	6·72	13·19	0·0	0·0165	0·0025
	Nov. 30, ,,	Same after fermentation -	10·99	0·0	12·98	0·0	0·0016	0·0164
		Results of fermentation -	– 0·06	– 6·72	—	—	– 0·0149	+ 0·0139

Experiments 1 and 1a show that for the consumption of 6·48, 7·09, and 7·07 c.c. of oxygen, ·00224, ·0024, and ·00248 grm. nitrous nitrogen were respectively formed.

If we raise each of these volumes to 10 c.c. for convenience of comparison, then the quantities of nitrous nitrogen formed will be ·00344, ·0033, and ·00351 respectively.

The volume of oxygen theoretically equivalent to the average of these three quantities is 8·14 c.c. Thus it is seen that the volume of oxygen consumed during the fermentation of ammonia in the absence of all organic matter is in excess of that theoretically equivalent to the nitrous acid formed in the proportion of 10 : 8·14. This means that 18·6 per cent. of the total oxygen absorbed was taken up by the synthesis of constructive materials for new nitrogen-oxidising organisms.

On turning to the result of the experiment with ammonium chloride and peaty matters, the influence of the latter during fermentation is at once seen. Not only is the quantity of nitrous and nitric acids greater in the presence than in the absence of these substances, but the product of oxidation is almost entirely nitric acid, and not, as in their absence, nitrous acid, the oxygen consumed being much the same in both cases.

If we raise the volume of oxygen to 10 c.c., as in the case of foregoing results, we find that for 10 c.c. of oxygen consumed, ·00024 grm. nitrous, and ·00408 grm. nitric, nitrogen were formed. These two weights are theoretically equivalent to ·5036 and 13·02 c.c. of oxygen respectively, on the assumption that they were both derived directly from ammonia.

Thus the volume of oxygen consumed in this experiment is less than that equivalent to the nitrous and nitric acids formed, in the proportion of 10 : 13·52.

THE ABSORPTION OF CARBON DIOXIDE DURING A SECOND STAGE FERMENTATION.

We have now to consider the determinations of the carbon dioxide in these last experiments, 2 and 3. These show that, although the peaty matters must have so largely entered into the chemical changes during fermentation, no carbon dioxide was formed, and but very little could have been fixed, the small difference recorded in the table being possibly largely due to experimental errors.

It is possible, also, since the ammoniacal nitrogen absorbed was slightly in excess of the total nitrogen oxidised, that none of the latter was derived from the peat.

The loss of carbon dioxide shown by the Experiments 1 and 1a with the inorganic solution are important in showing that the carbon fixed must be very small compared with the nitrogen oxidised, and therefore they add additional evidence to that already given by Winogradsky, who showed by a process of wet combustion that the assimilation of one part of carbon was accompanied by the oxidation of about 35 parts of nitrogen as ammonia to nitrous acid.* The mean loss of carbon dioxide shown by the determinations for the Experiment 1a, is ·15 c.c., which is equivalent to ·00008 grm. carbon; the ratio of it to that of the mean of the two quantities of nitrous nitrogen recorded for the same experiment, viz., ·00244 grm., is as 1 : 30·5.

In several experiments recorded in the paper from which these tables are quoted, it appears that very definite volumes of carbon dioxide are sometimes fixed, presumably during the formation of organic substances, but in all these experiments either peaty matters or fermented animal organic bodies were present during fermentation.†

It may be concluded, therefore, that the presence of some forms of peaty matters, and also fermented animal matters, increases the quantity of carbon dioxide which may be fixed during a fermentation of ammonia.

THE FERMENTATION OF NITROUS ACID TO NITRIC ACID.

Referring now to the Experiment No. 3 with potassium nitrite, it will be seen that, as in the case of Experiment No. 2 with ammonia and a portion of the same solution of peat, no carbon dioxide was formed, and little or none was fixed, so far as chemical analysis could detect. The volume of oxygen theoretically required to oxidise the quantity of nitrous nitrogen which was converted during fermentation to nitric acid is 11·12, a volume much in excess of that actually consumed.

It is impossible to suppose that this large excess of oxygen was derived from the quantity of peat present. Possibly intermediate combinations were formed during fermentation between the peaty matters and the nitrous acid, and that part at least of the nitric acid found after fermentation was formed from these combinations.

It is instructive to compare the results from Experiment 2 with those obtained from Experiment 1a in Table 18. In the former experiment an almost pure nitric fermentation, accompanied by the fixation of little, if any, carbon dioxide, occurred, while in the latter the fermentation was purely nitrous, accompanied by the formation of a large volume of carbon dioxide. And yet in both experiments dilute solutions of peat were employed, and in each a decided excess of ammonia remained after fermentation. There was, however, one distinct difference between the two solutions. The one employed for the first-mentioned experiment had previously undergone several steps of fermentation before being employed in this experiment, while the solution of peat employed for the latter experiment was a comparatively fresh one.

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* Annales de l'Institut Pasteur, vol. 4, pp. 213, 257, 760; vol. 5, pp. 92, 577.

† *Loc. cit.*, pp. 576, 588, 597.

On referring to the last table, 19, it will be found that the three solutions employed for these experiments were seeded with similar organisms. Hence it may be taken for granted that, although the differences in fermentative changes in each solution were possibly the result of the activities of different organisms, the changes in each solution were dominated by its chemical composition.

SUMMARY OF THE RESULTS OF EXPERIMENTS ON THE COURSE AND NATURE OF THE CHANGES WHICH OCCUR DURING THE SECOND STAGE OF FERMENTATION IN POLLUTED WATERS.

We may draw the following general conclusions as regards the various phases of chemical change which may occur during nitrification of ammonia or of nitrous acid, when these are associated with nitrifiable organic substances in the presence of mixed water organisms, and under varying conditions of dilution and of relative proportions :—

1. When the proportion of nitrifiable organic substances is large compared with that of ammonium compounds, a change may occur in which the ammonia is taken up, presumably to form new compounds with the organic substances, since the nitric acid formed is relatively very small, while very decided volumes of carbon dioxide are formed.

The volume of oxygen consumed is decidedly in excess of that theoretically equivalent to the oxidised inorganic products formed during the fermentation.

2. When the same solution is diluted, the fermentation may take a different course ; the volume of carbon dioxide formed is decided, and the ammonia becomes entirely absorbed as before, but the oxidised inorganic nitrogen product is practically exactly equivalent to the ammonia absorbed.

The oxygen consumed is practically equal to that theoretically equivalent to the inorganic oxidised products formed.

3. Only nitric acid appears to be formed in the solution under the stated conditions.

4. When the quantity of peaty matter is not large in proportion to that of the ammonium compounds, a fermentation may occur, during the earlier steps, of which intermediate combinations between the peaty matters and the ammonia appear to take place, since during such steps the oxidised inorganic nitrogen compounds formed are not equivalent to the ammoniacal nitrogen taken up, while during later steps they are found relatively to increase in quantity, and finally to become equivalent to it. Under these conditions the volume of carbon dioxide formed may be relatively extremely small.

The volume of oxygen consumed is under these circumstances very much less than that equivalent to the total oxidised inorganic products of the fermentation.

5. With the conditions stated in Paragraph 4, it appears that the nitrogen fermentation is both nitric and nitrous, the former predominating.

6. When the solution referred to in the same paragraph is diluted, the course of fermentation is much modified. From the first a large volume of carbon dioxide is formed, and the oxidised inorganic nitrogen is practically equivalent to the ammonia absorbed. When, further, the fermentation is pushed to completion, both peaty matters and ammonia appear to undergo nearly complete oxidation to inorganic products.

The volume of oxygen consumed may be, under these conditions, also very much less than that equivalent to the total oxidised inorganic products of the fermentation.

7. It is to be noted that the nitrogen fermentation in the dilute solution is both nitric and nitrous, the latter predominating, at least in the earlier steps of the fermentation.

8. The changes which peaty matters may undergo in the presence of decided quantities of ammonia during fermentation may vary with their nature, that is, whether they are fresh or have previously undergone some steps of nitrification.

9. Second stage fermentative changes can only proceed in the continual presence of dissolved oxygen. They cease altogether under anaerobic conditions, and no other changes, such as those which occur if anaerobic conditions are established during the first stage fermentation, are set up.

DEDUCTIONS FROM THE FOREGOING EXPERIMENTS ON THE COURSE AND NATURE OF THE CHANGES WHICH OCCUR DURING A SECOND STAGE FERMENTATION.

On reviewing the results of the foregoing experiments, we find that the oxidation of ammoniacal nitrogen to nitrous and nitric acid constitutes the central feature of a second stage of fermentation, just as the oxidation of organic carbon to carbon dioxide constitutes the central feature of the first stage. It is evident, therefore, that the products, nitrous and nitric acids, of the one stage are the analogues of the product, carbon dioxide, of the other. We may consequently term the two stages of fermentation the carbon oxidation stage and the nitrogen oxidation stage.

It is well known that dilute solutions of ammonia cannot be oxidised beyond nitrous acid during a second stage fermentation in the absence of nitrifiable organic substances, although both nitrous and nitric acid forming organisms may be present.* It is shown by the experiments, which have been summarised, that the presence of these substances is necessary for the oxidation of ammonia to nitric acid.†

The changes which nitrifiable organic substances may undergo appears from the experiments to be very variable. For example, when fresh, a portion of their carbon is readily oxidised to carbon dioxide; and then, if they be unassociated with ammonium compounds, they cease to undergo much further change.

These experiments therefore confirm the observations which Frankland made with reference to the oxidation of peaty matters, viz., that the carbon which it contains disappears much more rapidly than the nitrogen. He found that the proportion of carbon to nitrogen may be :—

In peat	11·4 : 1
In unoxidised peaty matters in upland surface waters	11·9 : 1
In the same after exposure in lakes and large reservoirs	5·9 : 1
In spring water containing peaty matters	3·3 : 1‡

When both nitrifiable organic substances and ammonium compounds are present together in a polluted water, both may be completely fermented, if the latter be in excess.

The volume of oxygen actually absorbed in the second stage of fermentation does not bear a constant ratio to the oxygen theoretically equivalent to the nitrous and nitric acids formed. The volume may be greater than the theoretical, *e.g.* 10 : 8·14, if nitrifiable substances are wholly absent, or less, *e.g.* 10 : 13·5, if these are present in large quantities and freshly formed.

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* Boulanger and Massol have showed that ammonia inhibits the development of nitric-acid-forming organisms, but not their activity when once developed. Annales de l'Institut Pasteur, XVII. and XVIII.

† Purvis and Coleman have recently shown, Jour. Roy. San. Inst., 1906, pp. 433–441, that sea water exerts a very decided retarding effect on nitrification.

‡ Rivers Pollution Commission, 6th Report, pp. 6-10. *See* also article on "Water," by P. Frankland, in Thorpe's Dictionary.

Where, as in ordinary cases of polluted tidal waters, nitrifiable organic substances are unlikely to be present in any but small proportions; the volume of oxygen required for the nitrification of the ammonia which they contain can be calculated with sufficient accuracy from the equation—

$$2\ NH_3 + 4\ O_2 = N_2\ O_5 + 3\ H_2O$$

PART VI.

THE CLASSIFICATION OF ORGANIC SUBSTANCES TO BE FOUND IN POLLUTED WATERS ACCORDING TO THEIR FERMENTATIVE PROPERTIES.

It follows from the experiments which we have considered, and from the conclusions which are deducible from them, that the fermentable matters which occur in polluted waters may be divided into three classes, thus, (1) The organic matters which are capable of undergoing the first stage of aerobic fermentation; (2) The organic matters which have already undergone that stage, but which will undergo further change during the second stage of fermentation; (3) Ammonium compounds which also undergo fermentative change during the second stage.

It is taken for granted that antiseptic substances are excluded, since they should never be allowed to escape with polluting matters into tidal waters in quantities sufficient to interfere with subsequent fermentation.

The first class probably includes nearly every known organic substance, except antiseptics. Munro showed some years ago in a paper entitled "The Formation and Destruction of Nitrates and Nitrites in Artificial Solutions and in River and Well Waters,"* that not only are such simple bodies as acetates and oxalates attacked by the organisms usually present in soils and water, but also such unlikely substances as ethylamine, cyanides and thiocyanates, and he concludes that it would be difficult to make out a list of organic compounds which are not fermentable when dissolved in natural waters and submitted to the action of the mixed organisms contained in them. Especially is this true in the case of mixtures of organic substances when dissolved in natural waters.

There appears to be, however, some exceptions to this rule. For example, one of the authors (Adeney) has observed that some of the aniline dyes resist fermentative change to a remarkable degree. When crude sewage is coloured with methylene blue, it may be completely fermented without the colouring matter being appreciably affected, except under anaerobic conditions, when the colour is discharged; but even then the colouring matter is not destroyed, since the colour returns on the liquid becoming re-aerated.

As regards the second class of substances, it includes, as we have seen, the organic matters in peaty coloured river waters and in the humus of cultivated soils, the organic matters found in drinking waters, and in polluted waters purified by aerobic bacterial fermentation.

It has been suggested that the first stage of fermentation should be designated by the terms bacteriolysis or aerobiolysis, and that the use of the term nitrification should be restricted to the second stage. The terms carbon oxidation and nitrogen oxidation, however, more accurately describe the two stages of change; and it is important that it should be clearly indicated that none of these fermentative changes take place without heat evolution.

With the employment of these terms we may also adopt the classification of the bodies which occur in polluted waters, into—

(1) Carbon-oxidisable bodies, or carbon-fermentable, or all fermentable organic substances which have not undergone carbon-oxidation.

(2) Nitrifiable or nitrogen-fermentable organic substances, that is, organic bodies which have suffered carbon-oxidation.

(2a) Ammonium compounds.†

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* C. S. J., vol. xlxxxi., p. 677. *See* also p. 651.

† "The Course and Nature of Fermentative Changes in Natural and Polluted Waters," Trans. Royal Dublin Society, 1897, pp. 270–271.

PART VII.

THE DIRECT ABSORPTION OF DISSOLVED OXYGEN BY DE-AERATED POLLUTED WATERS AND BY DIRECTLY AND EASILY OXIDISABLE SUBSTANCES.

We have so far considered the absorption of dissolved oxygen from indirect fermentative causes. As stated in the introduction to this section, polluted waters may *directly* affect the aeration of waters with which they may become admixed, owing to their state of possible de-aeration, and owing to their possibly containing easily oxidisable substances.

Thus, if de-aerated liquid sewage matters be mixed in equal proportions with unpolluted waters, the aeration of the latter will be immediately reduced by one-half; and this will be irrespective of the strength of the sewage as regards fermentative substances. It may result from an otherwise good effluent, if it be de-aerated.

If, therefore, a sewage effluent is discharged, in large proportions, into a narrow tidal way by reason of its high degree of purification, it is important to consider the state of aeration, since, if this be low, it may possibly reduce that of the tidal water to a dangerous degree, notwithstanding its otherwise good qualities.

But little attention appears to have been given to the state of aeration of sewage or of sewage effluents at the time of discharge into tidal waters. It may be safely assumed, however, that effluents from septic tanks, or from precipitation tanks, are completely de-aerated; so also effluents from contact beds. A number of analyses of effluents of this description by one of the authors (Letts)* is given in the subjoined table. It will be seen that in every case they were practically free from dissolved oxygen at the time of collection.

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* Report on the Scheme of Sewage Purification proposed for Belfast, and its probable effects on the Lough, p. 29.

TABLE 20.—Showing State of Aeration as well as the Composition

Series.	Date.	Nature of the Sample.	Rainfall at 9 a.m. on day of collection for past 24 hours. (ins.)	Parts per 100,000.							Cubic centimetres per litre at N.T.P.			
				Solids.						Total.	Dissolved Gases.			
				Suspended.			Dissolved.							
				Fixed	Volatile	Total.	Fixed	Volatile	Total.		Carbonic anhydride.	Oxygen.	Residual Gases.	Total.
1	Jan. 6 (Sun.)	Sewage - -		3·4	10·7	14·1	81·4	22·0	103·4	117·5	122·97	0	18·06	141·03
		First Effluent -	0	–	–	–	–	–	–	–	130·60	0	18·43	149·03
		Second Effluent*		?	?	?	137·0	25·0	162·0	162·?	126·72	0·19	20·06	146·97
2	Jan. 20 (Sun).	Sewage - -		4·0	4·4	8·4	73·7	17·1	90·8	99·2	89·56	0	18·26	107·82
		First Effluent -	0·06	–	–	–	–	–	–	–	94·76	0	19·26	114·02
		Second Effluent*		?	?	2·3	90·4	15·6	106·0	108·3	88·70	0	18·87	107·57
3	Jan. 29 (Tues.)	Sewage - -		2·7	8·6	11·3	89·8	17·2	107·0	118·3	102·37	0	18·89	121·26
		First Effluent -	0·08	–	–	–	–	–	–	–	104·28	0	19·77	124·00
		Second Effluent*		1·3	1·1	2·4	87·7	13·4	101·1	103·5	99·64	0	20·24	119·88
4	Feb. 5 (Tues.)	Sewage - -		3·1	12·2	15·3	85·7	22·2	107·9	123·2	102·12	0·05	18·89	121·06
		First Effluent -	0·005	–	–	–	–	–	–	–	109·36	0	19·74	129·10
		Second Effluent*		1·2	2·6	3·8	87·7	13·6	101·3	105·1	105·59	0	20·12	125·71
5	Feb. 12 (Tues.)	Sewage - -		2·7	9·0	11·7	135·6	28·9	164·5	176·2	110·91	0	18·08	128·99
		First Effluent -	0·010	–	–	–	–	–	–	–	125·41	0	19·82	145·23
		Second Effluent*		?	?	2·4	122·2	21·6	143·8	146·2	118·55	0	20·85	139·40
6	Feb. 19 (Tues.)	Sewage - -		1·7	12·7	14·4	161·4	37·3	198·7	213·1	108·83	0	18·04	126·87
		First Effluent -	0·016	–	–	–	–	–	–	–	128·72	0	18·97	147·69
		Second Effluent*		1·2	2·9	4·1	150·9	24·3	175·2	179·3	129·14	0	21·00	150·14
7	Mar. 3 (Sun.)	Sewage - -		10·5	8·0	18·5	65·3	14·2	79·5	98·0	87·10	1·99	16·70	105·79
		First Effluent -	0·43	–	–	–	–	–	–	–	–	–	–	–
		Second Effluent†		?	?	1·7	97·3	12·5	109·8	111·5	91·56	0	18·65	110·21
8	Mar. 10 (Sun.)	Sewage - -		?	?	6·7	92·4	19·7	112·1	118·8	107·37	0	18·11	125·48
		First Effluent -	0	–	–	–	–	–	–	–	–	–	–	–
		Second Effluent†		0·4	2·7	3·1	100·5	13·5	114·0	117·1	124·16	0	19·84	144·00
9	Mar. 22 (Fri.)	Sewage - -		1·1	15·2	16·3	129·4	41·3	170·7	187·0	98·27	0	17·36	115·63
		First Effluent -	0	–	–	–	–	–	–	–	–	–	–	–
		Second Effluent†		2·2	4·5	6·7	130·8	20·5	151·3	158·0	124·43	0	20·79	145·22
10	May 17 (Fri.)	Sewage - -		0·9	31·1	32·0	293·4	72·6	366·0	398·0	104·95	0	17·15	122·10
		First Effluent -	0	–	–	–	–	–	–	–	–	–	–	–
		Second Effluent†		?	?	1·7	229·8	44·2	274·0	275·7	112·77	0	16·18	128·95
11	May 31 (Fri.)	Sewage - -		3·9	18·2	22·1	223·9	48·1	272·0	294·1	95·64	0	16·03	111·67
		First Effluent -	0·31	–	–	–	–	–	–	–	–	–	–	–
		Second Effluent†		1·8	6·7	8·5	192·4	33·6	226·0	234·5	126·15	0	15·19	141·34
12	June 7 (Fri.)	Sewage - -		1·7	12·7	14·4	223·2	50·3	273·5	287·9	115·30	0	17·19	132·49
		First Effluent -	0	–	–	–	–	–	–	–	–	–	–	–
		Second Effluent†		?	?	5·4	231·5	33·3	264·8	270·2	158·22	0	15·68	173·90

* Samples for dissolved gases collected from mid depth of Bacteria Bed.
† " " " " 6 inches below the surface of Bacteria Bed.

OF SAMPLES OF SEWAGE AND EFFLUENTS (*Letts*).

Parts per 100,000.									
Nitrogen as :—						Oxygen absorbed Test at 80 F.—After.			Chlorine.
Unoxidised.				Oxidised.					
Free Ammonia.	Albumenoid Ammonia.	Sum of Free and Albumenoid Ammonia.	Total. (Kjeldah.)	Nitrites.	Nitrates.	3 Minutes.	4 Hours.	5 Days' Incubation (3 Minutes).	
3·62	0·92	4·54	5·60	0	0	–	10·87	–	54·4
2·43	0·39	2·82	2·63	0	0	–	4·68	–	60·0
1·48	0·16	1·64	2·31	0	0	–	2·56	–	63·8
1·48	0·66	2·14	2·31	Traces.	0·04	1·88	6·89	3·68	28·7
0·82	0·33	1·15	0·99	0	0	0·83	2·84	0·90	35·0
0·39	Traces.	0·39	0·82	0	0·04	0·30	1·87	0·45	38·0
1·84	0·58	2·42	2·96	0	0	1·82	6·00	5·34	36·2
1·15	0·53	1·68	2·04	0	0	1·12	3·02	0·72	35·2
0·74	Traces.	0·74	0·91	0	0·08	0·56	1·52	0·62	35·1
1·56	0·74	2·28	2·80	0	0	2·34	8·38	5·11	34·2
1·07	0·33	1·40	1·56	0	0	1·10	3·22	2·21	34·7
0·66	Traces.	0·66	0·66	0	0·04	0·78	2·15	0·85	34·9
2·47	0·74	3·21	3·62	0	0	2·44	8·44	6·52	64·8
1·90	0·41	2·31	2·55	0	0	1·29	3·67	1·80	57·5
1·32	0·36	1·68	1·73	0	0·10	0·86	2·35	1·07	56·5
2·30	0·91	3·21	4·12	0	0	3·11	9·73	8·98	80·0
1·58	0·56	2·14	2·80	0	0	1·66	4·85	3·62	75·5
1·32	0·39	1·71	1·81	0	0·02	0·91	3·07	1·42	72·2
1·15	0·41	1·56	2·14	0	0·18	1·61	4·65	2·45	23·1
0·82	0·20	1·02	1·23	0	0	0·73	1·55	0·99	32·6
0·46	0·20	0·66	0·91	0	0·08	0·48	1·28	0·40	40·0
1·65	0·50	2·15	2·31	Traces.	0·10	1·67	5·52	3·02	38·0
1·05	0·30	1·35	1·73	0	0·02	1·20	3·28	1·55	40·2
0·74	0·20	0·94	1·07	0	0·06	0·60	1·68	0·69	41·2
1·90	1·05	2·95	3·46	0	0·04	3·49	9·37	8·39	61·5
1·25	0·72	1·97	2·80	0	0	2·18	7·25	6·13	61·5
0·90	0·41	1·31	1·65	0	0	1·20	3·60	1·98	61·5
2·39	1·91	4·30	5·43	0	0	5·55	18·81	8·40	158·6
2·24	0·91	3·15	3·46	0	0	3·21	9·29	8·77	138·6
1·56	0·49	2·05	2·77	0	0	1·71	4·81	3·26	122·1
2·04	0·91	2·95	3·79	0	0·02	3·58	9·66	10·05	118·5
1·65	0·59	2·24	2·72	0	0	2·01	5·67	4·97	107·3
1·07	0·39	1·46	1·89	0	0	1·15	2·89	1·78	100·3
3·21	1·40	4·61	5·43	0	1·31	4·07	9·85	11·44	117·7
2·63	0·99	3·62	3·82	0	0·12	2·71	7·51	7·46	119·2
1·81	0·53	2·34	2·63	0	0·00	1·51	3·70	2·66	121·4

Dr. McGowan has given in his Report to the Royal Commission on Sewage Disposal, on "The Land Treatment of Sewage."* determinations of dissolved oxygen in a large number of effluents from land treatment, which show that the aeration at the time of collection may vary from about half the air saturation value, at 15° C., to zero.

It is probably safe to assume that only very good effluents from land treatment, or from slow intermittent filtration, are likely to be aerated to a degree shown by Dr. McGowan's analyses, viz., 4 c.c. oxygen per litre.

Again, if crude sewage, which contains easily oxidisable chemicals or products of putrefaction, be discharged into a tidal way by reason of its comparatively small bulk, it may have a much more serious effect upon the aeration of tidal waters than appears to be generally recognised; the solids, moreover, may form permanent deposits along the bed, and these will undergo anaerobic ferment, the reduced products of which will cause a direct de-aeration of the water as already indicated.

Experiments bearing upon the effect of easily oxidisable substances in polluted waters will be described later on, Tables 35, 36 and 37.

PART VIII.

1. THE INFLUENCE OF NITRATES AND NITRITES ON FERMENTATIVE CHANGES IN POLLUTED WATERS

The influence of these bodies on fermentation, when present in sufficient quantity, is now well acknowledged. They prevent putrefaction. One of the authors (Adeney) showed some years ago that the first stage of aerobic fermentation of a sample of sewage could be completed in the presence of a supply of nitrate of soda. The following are the results of analysis, expressed in parts per 1,000, of a sample of sewage to which had been added an excess of nitrate of soda, before and after keeping it for two months out of contact with the air† :—

—	CO_2	O_2	N_2	N as NH_3
Before - -	80·87	3·8	17·57	0·06
After - -	315·0	0	24·29	0·08
	+224·13	– 3·8	+6·72	+0·02

A portion of the sample of sewage when mixed with tap water and allowed to ferment, yielded 250 c.c. carbon dioxide per litre on completion of first stage of fermentation.

The results of a series of experiments with nitrated sewage has recently been published by one of the authors (Letts). They are given in the following table‡ :—

TABLE 21.—DISSOLVED Gases found in Septic Tank Effluents (A) with added Potassium Nitrate and (B) alone, after certain Intervals of Time. (Letts).
(Results in Cubic Centimetres Per Litre at 0°C. & 760 mm.

	——	1	2	3	4	5	6
						Non-Aerated	Aerated
	Nitric Nitrogen added in parts per 100,000 - - - - -	2·5	5·0	2·5	2·5	2·5	2·5
	Time interval in hours - - -	48	24	24	24	24	24
A. Nitrated Sample	Carbonic Anhydride - -	169·97	155·68	153·34	158·01	165·85	149·63
	Nitrogen - - - - -	38·12?	29·40?	34·21?	32·41	36·16	33·53
	Nitric Oxide - - -	?	?	6·99	6·31	0·00	0·00
	Marsh Gas - - -	?	?	?	3·37	2·63	0·00
	Oxygen - - - - -	0·00	0·00	0·00	0·00	0·00	0·00

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* Fourth Report of the Royal Commission on Sewage Disposal. Vol. IV., Part II.

† "Recent Advances in Bacterio-chemical Study of Sewage." Proceedings of Civil Engineers of Ireland, 1896.

‡ Second Report on the Scheme of Sewage Purification for Belfast, 1904.

	—	1	2	3	4	5	6
B Septic Tank Effluent.	Carbonic Anhydride -	126·68	150·99	118·10	127·31	120·44	92·52
	Nitrogen - - -	18·84	18·86	15·62	16·55	16·48	13·94
	Marsh Gas - - -	?	?	1·91*	2·92	1·72	0·14?
	Oxygen - - -	0·00	0·00	0·00	0·00	0·00	0·00
Differences.	Carbonic Anhydride (Excess in Nitrated Sample) -	43·29	4·69	35·24	30·70	45·40	57·11
	Nitrogen as Nitrogen and Nitric Oxide (Excess in Nitrated Sample) - -	19·28?	10·54?	22·08?	19·12	19·68	19·59
	Marsh Gas (Excess in Nitrated Sample) - - -	?	?	?	0·45	0·91	–0·14?

* Marsh Gas - - - 1·48 } 1·91
Hydrogen - - - 0·43 }

There can be little doubt that nitrates can act as a substitute for dissolved oxygen for the first stage of fermentation of the organic matters in sewage. But when both are present, the dissolved oxygen is completely absorbed before the nitrates are apparently affected. This point is well illustrated by some analytical results recorded by one of the authors (Adeney) in the paper just quoted. Two samples of slightly polluted water were collected from two points along a small stream, one a little below the other, and analysed with the following results, which are expressed in parts per 1,000 :—

	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
1	116·05	5·99	15·08	0·0044	0·00024	0·00992
	123·68	0	17·17	0·005	0	0·009
	+ 7 63	– 5·99	+ 2·09	+ 0·0006	– 0·00024	– 0·00092
2	116·39	7·38	15·58	0·0013	0·00018	0·01084
	119·71	0	15·63	0·0006	0·00016	0·01174
	+ 3·22	– 7·38		– 0·0007	– 0·00002	+ 0·0009

In the results given for Sample 1, the characteristic changes of a first stage fermentation are seen. It is also observable that the dissolved oxygen originally present was insufficient for this process, and that the nitrates were drawn upon for a further supply of that gas. The proof of this lies in the increased volume of nitrogen found after fermentation, and the decrease in quantity of nitrates and nitrites. The results recorded for Sample 2 show that the fermentative process which occurred in the water collected from the lower point in the stream was largely confined to that of nitrification.

The foregoing results are confirmed by some experiments which have been made by Dr. Gilbert J. Fowler*, and also by some experiments quite recently made by one of the authors (Letts). The results are recorded in the two subjoined Tables. The results of these experiments not only show that dissolved oxygen is absorbed before nitrates and nitrites are appreciably reduced, but also that the latter bodies do act as oxygen carriers and prevent putrefaction during bacterial fermentation.

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* Annual Report of the Rivers Department of the City of Manchester for year ending March 27th, 1901, Table 22.

TABLE 21A.—Experiments showing the Effect of Incubation on Dissolved Oxygen and Nitrates. Determinations are recorded of the actual amounts of the Dissolved Oxygen and of Nitrates and Nitrites in the Filtrate from one of the Bacteria Beds of the Manchester Sewage Works at Davyhulme, in samples of the Manchester Ship Canal Water collected immediately above Barton Locks, and in mixtures in equal parts of the two, both before and after Incubation at 27·7 C. for 48 hours (Fowler). The dissolved oxygen is stated in c.c. at N.T.P. per 1,000 c.c. of water, the other constituents in parts per 100,000.

Date.	NH_3 from Nitrites.			NH_3 from Nitrates and Nitrites.			Dissolved Oxygen.			3 Minutes' Oxygen Absorption.					
	Before Incubator.		After Incubator.	Before Incubator.		After Incubator.	Before Incubator.		After Incubator.	Before Incubator.			After Incubator.		
	Filtrate.	Ship Canal Water.	Filtrate and Canal Water.	Filtrate.	Canal Water.	Filtrate and Canal Water.	Filtrate.†	Canal Water.†	Filtrate and Canal Water.	Filtrate.	Canal Water.	Filtrate and Canal Water.	Filtrate.	Canal Water.	Filtrate and Canal Water.
1900.															
January 18	·029	—	·356	·8	·27	·69	5·4	6·0	0	·2	·57	·37	·13	·4	·37
„ 20	·019	—	·029	·9	·23	·54	4·9	7·5	0	·19	·66	·51	·2	·4	·43
„ 22	trace	—	·13	1·37	·26	·83	5·0	7·5	0	·2	·5	·29	·06	·2	·26
„ 24	·019	·17	·056	1·1	·34	·61	5·1	5·2	0	·27	·63	·37	·2	·37	·34
„ 25	·014	·071	·043	1·1	·256	·47	5·6	5·5	0	·3	·63	·4	·09	·34	·37
„ 27	0	trace	·17	·86	·19	·4	4·9	5·0	0	·23	·46	·34	·2	·37	·43
„ 29	·014	·029	trace	1·47	·17	·83	5·3	5·8	0	·23	·40	·31	·20	·37	·29
„ 30	trace	·021	·11	1·29	·31	·61	5·0	6·0	0	·26	·40	·31	·24	·34	·31
„ 31	0	·043	·086	·97	·30	·56	4·8	5·7	0	·31	·60	·46	·29	·51	·49
February 3	·014	·043	·014	·86	·27	·26	3·5	2·6	0	·24	·57	·37	·16	·49	·34
„ 5	·009	·14	·043	1·50	·30	1·04	4·9	1·1	0	·29	·83	·63	·21	·57	·26
„ 6	·036	·29	·014	·90	·29	·83	4·2	0	0	·51	·94	·74	·23	·69	·29
„ 10	·014	·029	·014	·71	·19	·26	4·0	3·2	0	·30	·74	·51	·27	·63	·29
„ 12	·014	·057	·036	1·2	·21	·54	5·1	2·6	0	·27	·91	·57	·23	1·00*	·34
„ 13	trace	·014	·029	·83	·26	·09	5·2	2·8	0	·24	·91	·57	·21	1·20*	·49
„ 14	·014	·014	trace	·80	·19	·07	4·8	1·8	0	·29	1·3	·71	·20	1·57*	·74

,,	15	·021	—	·021	·90	·21	·06	5·4	5·8	0	·21	1·14	·70	·21	1·29*	·57
,,	17	·029	·086	·029	1·11	·31	·46	5·1	7·8	0	·16	·43	·26	·06	·34	·23
,,	19	·029	·17	—	·97	·26	·61	6·3	7·3	0	·26	·63	·43	·14	·37	·37
,,	20	—	—	—	—	—	·70	6·0	7·0	0	·29	·46	·29	·19	·34	·23
,,	21	·004	·07	·057	1·11	·31	·46	5·3	6·1	0	·27	·51	·37	·19	·40	·34
,,	22	·011	·029	·029	1·11	·23	·73	5·0	7·2	0	·27	·71	·51	·21	·54	·51
,,	24	·014	·071	·043	·71	·27	·46	4·0	5·6	0	·21	·40	·31	·20	·31	·29
,,	26	·03	—	·20	1·33	·36	·73	3·8	6·1	0	·29	·63	·46	·17	·29	·37
,,	27	·021	·057	·23	1·04	·34	·53	5·2	6·7	0	·17	·34	·23	·16	·26	·20
,,	28	·009	·13	·37	1·07	·27	·60	4·9	5·1	0	·27	·43	·37	·23	·40	·26
March	1	·043	0	·43	·86	·30	·67	5·4	5·2	0	·20	·31	·26	·17	·26	·34
,,	3	·036	·042	·007	·79	·19	·26	4·3	4·2	0	·27	·57	·43	·26	·37	·43
,,	5	·014	·11	·007	1·26	·31	·61	5·2	2·9	0	·23	·40	·31	·20	·46	·31
,,	6	·029	·20	·021	·79	·24	·43	4·0	1·4	0	·24	·57	·41	·26	·83	·37
,,	7	·033	·13	·029	·64	·24	·33	4·2	1·6	0	·37	·71	·54	·30	·83	·51
,,	8	·006	·06	·014	·61	·24	·11	4·3	5·0	0	·31	·66	·49	·21	·69	·51
,,	10	·021	·014	0	·93	·19	·12	4·6	1·3	0	·37	·86	·60	·34	1·03*	·34
,,	12	·036	trace	trace	1·71	·30	·44	4·3	1·7	0	·40	1·03	·71	·39	1·31*	·43
,,	13	·026	trace	trace	1·33	·11	·09	5·1	1·9	0	·41	1·00	·71	·41	1·37*	·54
,,	14	·029	0	0	·86	·06	·07	4·7	2·2	0	·31	1·06	·69	·30	1·43*	·69
,,	15	·05	trace	0	·86	·05	·27	5·0	0·9	0	·41	1·26	·83	·33	1·7 *	·77
,,	17	·026	0	0	·86	·09	·11	3·1	2·0	0	·14	·94	·54	·21	1·51*	·51
,,	19	·026	0	trace	1·3	·16	·31	—	—	0	·27	1·17	·71	·14	1·40*	·71
,,	20	·036	0	0	1·07	·036	·26	3·7	1·3	0	·31	1·1	·71	·24	1·46*	·69
,,	21	·019	0	0	·69	·021	·20	—	0·3	0	·46	1·26	·86	·31	1·6 *	·80
,,	22	·014	0	·019	·90	·021	—	4·5	0·6	0	·40	1·23	·80	·29	1·71*	·63
,,	24	·021	0	0	·57	0	—	4·0	1·9	0	·41	1·09	·74	·31	1·37*	·74
,,	26	·007	0	0	1·40	·007	·07	4·0	1·9	0	·43	1·03	·66	·27	1·34*	·94
,,	27	·009	0	0	1·14	·029	0	2·7	2·3	0	·51	1·03	·74	·44	1·43*	·91

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† The samples of filtrate and of Canal water used in these experiments were aerated subsequent to collection, and before intermixing.
* Samples thus marked were putrescent after incubation ; all the other samples remained sweet.

TABLE 21B.—Experiments showing the Changes which occur in a Nitrated Effluent when kept out of contact with air at 15° C. (Letts). The Effluent resulted from the treatment of a Septic Tank Effluent by a Ridgeway Sprinkler.

Series.	Date.	Time.	Dissolved (Gases c.c. per Litre at N.T.P.).				Nitrogen (parts per 100,000) as :—			
			CO_2.	O_2.	N_2.	Total.	Free Ammonia.	Albuminoid Ammonia.	Nitrite.	Nitrate.
A.	February 22nd, 1905	Shortly after collection	50·04	6·55	17·81	74·40	0·49	0·29	Traces	1·98
	" 27th, "	5 days " "	55·61	0·00	18·01	73·62	0·41	0·22	"	2·10
	March 3rd, "	9 " " "	14·94*	0·10*	18·43	—	0·49	0·20	"	1·85
	" 14th, "	20 " " "	61·18	0·00	19·74	80·92	0·49	0·20	"	1·85
	" 24th, "	30 " " "	64·78	0·00	21·85	86·63	0·58	0·16	"	1·65
B.	March 8th, 1905	Shortly after collection	39·21	6·84	17·21	63·26	0·44	0·19	Traces	2·31
	" 9th, "	24 hours " "	40·46	5·13	17·10	62·69	—	—	—	—
	" 13th, "	5 days " "	44·93	0·08	17·60	62·61	—	—	—	—
	" 15th, "	7 " " "	—	—	—	—	0·36	0·15	—	2·31
	" 30th, "	22 " " "	51·04	0·00	19·51	75·55	0·48	0·14	0·0	2·18
C.	March 16th, 1905	Shortly after collection	44·46	6·20	16·52	67·18	0·46	0·10	Traces	1·18
	" 20th, "	4 days " "	49·38	0·50	16·53	66·41	—	—	"	1·29
	" 23rd, "	7 " " "	50·57	0·00	16·86	67·42	0·33	0·07	"	1·51

* For this analysis the sample was drawn from the middle of liquid and not from the lower layers as in the previous analyses, as it was thought that the sediment might have affected the dissolved oxygen in the latter, and the trace of oxygen found is probably accounted for in this way. Moreover, in order to avoid the disturbing effects of nitrites on the dissolved oxygen in the presence of free acid, no acid was added when the dissolved gases were boiled out. This explains the low proportions of the carbon dioxide found.

Dr. McGowan makes the following statement in connection with this subject in his report already referred to, p. 326 :—

> "There appears to exist doubt in some minds as to whether an effluent, when left to itself, exhausts its dissolved oxygen before beginning to use up its nitrate, or whether both are utilised simultaneously. But we think that the various results bearing upon this point which we have obtained (and which are to be found in the various Chemical Tables of Analyses) are in accordance with the earlier observations of Adeney, which were based on the work of Munro (Journ. Chem. Soc., Vol. 49, p. 651) and of Gayon and Dupetit (Station Agronomique der Bordeaux, 1886), and strengthen the conclusion that, in accordance with chemical theory, the oxygen is consumed before the nitrate is touched, provided that the liquid is free from suspended organic matter. Should the latter be present, the upper layers of liquid might still conceivably contain some free oxygen, while the nitrate in solution in the lower layers was being attacked by adjacent organic matter in suspension."

The experiments which have been quoted make it evident that the real value of nitrates, when present in sewage or in effluents, in sufficient quantity, is that they ensure the absence of reduced products of anaerobic fermentation, which may not only be poisonous *per se*, but, as already pointed out, will consume the dissolved oxygen of waters with which they become mixed. Instances of the different effects of nitrated and of non-nitrated sewages when discharged into tidal waters will be found described in the section on the Estuary of the Liffey, pp. 282–288, 299–300.

2. INFLUENCE OF MANGANESE PEROXIDE ON FERMENTATIVE CHANGES IN SOLID SEWAGE MATTERS.

One of the authors (Adeney) has shown that freshly precipitated hydrated manganese peroxide, when mixed with solid sewage matters, exercises precisely similar functions towards them as nitrates and nitrites can do towards organic substances in solution. He noticed some years ago * that when the freshly precipitated peroxide was left immersed in sewage for four or five days, it became completely reduced to manganeous carbonate. He referred the reduction to the influence of water bacteria, and pointed out that the decomposition was probably analogous to the decomposition which nitrates undergo. It would then be expressed by the following equations :—

$$\begin{array}{ll} (1)\ 2MnO_2 & = 2MnO + O_2. \\ (2)\ C + O_2 & = CO_2. \\ (3)\ MnO + CO_2 & = MnCO_3. \end{array}$$

These reactions would be attended with the evolution of a considerable quantity of heat, and would therefore constitute a source of considerable energy to the bacteria, as shown from the following thermal data taken from Thomsen's "Thermochemische Untersuchungen" :—

$$\begin{array}{lcr} 2Mn, O, H^2O & = & 189{,}440 \\ 2Mn, O^2, H^2O & = & 232{,}660 \\ \hline & & -\ 43{,}220 \\ \hline C, O^2 & = & 96{,}960 \\ MnH^2O^2, CO^2\ Aq & = & 13{,}230 \\ \hline & & 110{,}190 \\ & & 43{,}220 \\ \hline & & 66{,}970 \\ \hline \end{array}$$

The same author also observed that freshly precipitated peroxide suffers reduction to manganous carbonate when it is mixed with *solid* sewage matters. He put this to test on a large scale, as already described, page 32.

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* "On the Reduction of Manganese Peroxide in Sewage," Scient. Pro. Roy. Dub. Soc., Vol. VIII. (1894), p. 247.

Some pieces of the reduced peroxide were submitted to analysis, with the following results :—

Insoluble mineral matter	12·16
Moisture	15·68
Organic matter insoluble in dilute HCl	4·0
Organic matter soluble in dilute HCl	4·35
MnO	24·6
CaO	2·7
Fe_2O_3 and Al_2O_3	10·06
MgO	1·6
Na_2O and K_2O	1·1
$(NH_4)_2O$	0·005
NiO, CoO, ZnO	traces
CO_2	18·98
SO_3	0·37
P_2O_5	0·59
Cl	trace
	100·695

It is evident from the above results that the manganese was present mainly as manganous carbonate. A careful examination was made for peroxide, but with negative results. An examination for nitrates was also attended with negative results.

No trace of sulphuretted hydrogen or other products of putrefactive fermentation, such as are invariably met with when sewage solid matters alone are kept under similar conditions, were detected.

The organic matters associated with manganous carbonate were found to be of considerable interest. A combustion of some of the air-dried substance gave the amount of organic carbon, after allowing for the inorganic carbon, as = 4·7 per cent., and a determination of the organic nitrogen by Kjeldahl's method gave 0·67 per cent.

As will be gathered from the Table giving the results of analysis, a portion of the organic matters present was taken up by the dilute acid employed for dissolving the substance. Practically, however, all was left undissolved when the solution was evaporated to dryness, and the residue treated with concentrated hydrochloric acid and water, in the ordinary way, for the separation of soluble silica. The organic matters, which were separated in this way, were brownish-black in colour, and were completely soluble in a dilute solution of sodium carbonate, giving rise to a solution of a deep brown colour. They seemed, in fact, closely associated in chemical and physical characters with the colouring matters of peat, and also with the colouring matters which are formed where soluble sewage-matters are oxidised by microbes in the presence of an excess of atmospheric oxygen. From the influence which the peroxide appears to have exerted on the products of fermentation of the organic matters with which it was associated, and the reduction and conversion into carbonate which itself suffered, it may fairly be concluded that the decomposition of the peroxide under the conditions described may be regarded as a fermentation consisting of the direct oxidation of organic carbon at the expense of the available oxygen of the peroxide ; that, in fact, the insoluble peroxide exerts, when mixed with solid fermentable matters, an influence, and undergoes a change, which nitrates and nitrites undergo when present in an over-polluted water.

PART IX.

THE DISSOLVED OXYGEN ABSORBED IN EACH STAGE OF AEROBIC FERMENTATION COMPARED WITH THE "OXYGEN CONSUMED" FROM ACID PERMANGANATE.

We have already stated that Dr. Dupré showed some years ago (1884) that the amount of dissolved oxygen taken up by natural waters, in which bacteria are active, is very much greater than the amount of oxygen which the same waters take up from a solution of permanganate. One of the authors (Adeney) confirmed this observation for polluted waters containing carbon-fermentable organic substances in one of his papers already referred to (1895), and further showed that in the case of waters containing only nitrifiable organic substances and ammonium compounds, the dissolved oxygen consumed by the fermentation of the former substances is probably much the same in volume as the " oxygen consumed " from acid permanganate. Thus the crude sewage employed for the experiments recorded in Table 10, p. 28, was carefully examined as regarded its " oxygen absorption " from standard acid permanganate during three hours in the cold.

The results showed that the volume of oxygen so absorbed was much less than that absorbed by a similar quantity of the same sewage from dissolved oxygen during the complete *first stage* fermentation, thus—

Oxygen absorbed from permanganate, per litre of sewage - - - -	50·2 c.c.
Dissolved oxygen absorbed on completion of the first stage of fermentation, per litre of sewage, Table 10 - - - - - - - - - - - -	127·0 c.c.

The sample of sewage effluent from a gravel filter bed which was employed for the experiments on the course of change during the second stage of fermentation, Table 14, p. 31, was also carefully examined as regards its " oxygen absorbed " from acid permanganate. It will be seen from the following results that the oxygen absorbed by the fermentation of the nitrifiable organic substances present in the sample could not have absorbed much dissolved oxygen, much the greater portion of it being taken up by fermentation of the ammonium compounds. The volume actually absorbed by them was less than the volume absorbed from acid permanganate. There is little doubt, however, that in the fermentation experiments the nitrifiable organic substances were not completely oxidised.

TABLE 22.—Experiments to compare the Volumes of Dissolved Oxygen Absorbed during a Second Stage of Fermentation, with the " Oxygen Consumed " from Standard Acid Permanganate during Three Hours in the Cold. The figures for the Fermentation Test are taken from Table 14, p. 31 (Adeney).

Volumes of gases expressed in c.c. per litre.				" Oxygen absorbed " from acid permanganate acting in the cold for three hours.
Sample.	Fermentation Test.			
	Carbon dioxide formed.	Oxygen = to N_2O_3 and N_2O_5 formed.	Volume of oxygen absorbed.	
Sewage effluent from a gravel filter bed.	15·8	42·44	48·88	16·2

One of the authors (Letts) and his pupils have also shown that no relation exists between the oxygen actually consumed by the fermentation of the carbon-fermentable organic matters in a polluted water, and the " oxygen absorbed " from acid permanganate.*

The experimental data from which this conclusion is drawn will be found in Table 27, page 70.

It will be sufficient to consider the figures obtained in Series 1 of this Table. First, if we take the results obtained from the " oxygen absorbed " test in the original mixture and contrast it with the oxygen actually absorbed in forty-eight hours, the figures are, respectively, 0·144 parts by weight per 100,000, and 3·21 c.c. per litre. The latter is equivalent to ·0046 grms. per litre, or 0·46 parts by weight per 100,000. In other words, the oxygen actually absorbed was about three times as much as the amount shown by the permanganate test.

Next, if we contrast the differences in different periods of the two tests, and translate them into the same units, we obtain the following figures :—

——	Dissolved oxygen actually disappearing after :—	Differences between " oxygen absorbed " originally, and after :—
6 hours - -	0·0043	0·018
24 hours - -	0·2996	0·036
48 hours - -	0·4602	0·063

The figures represent parts per 100,000, and should, of course, correspond if the oxygen of the permanganate acted in the same manner as the dissolved oxygen. This, of course, was not to be expected, but it is a remarkable fact that a more energetic oxidation is induced by organisms and free oxygen than by the permanganate solution.

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* *Loc. cit.*, *p. 340.*

The difference between the products of the action of permanganate and of living organisms on polluted waters is obviously due to the fact that the former are the result of partial chemical oxidation, while the latter are the result of a number of physiological processes, respiration, enzymic action, construction and excretion, set up by organisms in an active state of growth and multiplication.

PART X.

THE RATE OF RE-AERATION OF FRESH AND OF SALT WATERS AFTER BEING DE-AERATED BY POLLUTING MATTERS.

Before the subject of the rate of absorption of dissolved oxygen which may be allowed in polluted tidal waters within the limits of safety to fish can be usefully discussed, it will be necessary to gain as definite ideas as possible of the rate at which re-absorption from the air will take place under calm weather conditions.

It is known that the re-aeration of waters in calm weather, when they have become partially or wholly de-aerated by pollution, takes place with extreme slowness. Two experiments by one of the authors (Adeney) illustrate this in an instructive manner.

Experiment A.—A large cylindrical vessel, 18¼ inches deep, and 10 inches diameter, was fixed in a thermostat, and nearly filled with sea water, which had been previously boiled to expel the greater portion of the dissolved gases. The thermostat was kept at a constant temperature, 13·5°C.

Sea water saturated at 13·5°C. contains 11·67 c.c. nitrogen, and 6·00 c.c. oxygen, per litre.

No.	———	Time.	Gases at 0°C. and 760 mm., bar. per 1,000 volumes of water.	
			Nitrogen.	Oxygen.
1	Sample drawn from 16 in. below surface	At start	5·18	2·60
2	Ditto - - - - - - - -	19 hours later	6·63	3·28
3	Sample from 2 in. below surface - -	20 hours later	6·63	3·19
4	Sample from different parts of surface -	23 hours later	6·79	3·27
5	Sample from 16 in. below surface - -	42 hours later	7·67	3·77
6	Sample from surface - - - - -	48 hours later	7·75	3·70

After the last analysis had been made, a glass stirrer of gridiron form, 2 inches by 1 inch, was fixed so as gently to break the surface, and was mechanically rotated overnight with the following results:—

No.	———	Time.	Gases at 0°C. and 760 mm., bar., per 1,000 volumes of water.	
			Nitrogen.	Oxygen.
7	Sample from 16 in. below surface - -	69 hours later	11·64	5·74
8	Sample from surface - - - - -	70 hours later	11·70	5·75

Experiment B.—A tube 5 feet long and 1·8 inches diameter was filled with boiling sea water. It was then corked, and its contents allowed to cool out of contact with the air. When cold, the tube was uncorked and almost entirely immersed in a vertical position in a cold water jacket. The temperature of the jacket varied between 7·8 and 9·0°C., while the temperature of the layer of water in the tube above the jacket varied between 11·2 and 16·0°C.

No.	—	Time.	Nitrogen.	Oxygen.
1	Sample from the bottom of the tube - -	At commencement -	2·58	1·11
2	Ditto - - - - - - - - -	10 days later - -	7·78	3·13
3	Sample from 2 to 4 inches below surface -	10 days later - -	9·38	3·12
4	Sample from the bottom - - - - -	15 days later - -	7·79	3·12
5	Sample from 1 to 3 inches below surface -	15 days later - -	8·77	3·88
6	Sample from 1 to 3 inches below surface -	20 days later - -	9·42	4·23

After the last analysis had been made the tube was closed with an indiarubber cork fitted with an inlet and exit tube. The inlet tube dipped below the surface of the water to a depth of 1½ inches, and the exit tube was connected with a water pump, and a gentle current of air was drawn through the top layer of the water. The current of air was started at 12 p.m. and stopped at 4 p.m. on the same day, and the following samples were drawn and analysed:—

	Nitrogen.	Oxygen.
7.—Sample from the bottom - - - - - - -	9·95	4·39

The current of air was re-started at 5.30 p.m. and stopped at 10.30 next morning.

8.—Sample from the bottom - - - - - -	11·70	5·71
9.—Sample from surface layer - - - - - -	12·40	6·06

Sea water saturated at 10°C. contains 12·47 c.c. nitrogen and 6·45 c.c. oxygen per litre.

It is generally believed that the atmospheric gases, as they are dissolved by de-aerated water, remain more or less concentrated in the layer of water exposed to the air, and are only slowly circulated through the water by thermal currents and diffusion. The results of the experiments show that this belief is not well founded. They afford strong evidence to the contrary, since it is evident from them that the gases, as they are dissolved at the surface, pass through sea water with comparative rapidity. They also show that the slow rate of re-aeration is due to some retardation of the process of solution at the surface of the liquid exposed to the air.

Similar experiments have been made with distilled water, but they were not attended with quite similar results. The re-aeration of long columns of it have been found to take place more slowly, and a tendency of the dissolved gases to remain concentrated in the surface layers of the water has been revealed.

It will be observed that when the surfaces of the columns of de-aerated water in the experimental tubes were continuously broken by a mechanically driven stirrer, or by a slow current of air, the re-aeration of both sea and distilled water was greatly accelerated.

Hüfner in his work on the diffusion co-efficients of gases in water met with the phenomenon of the comparatively rapid downward passage or streaming of the dissolved gas, and in consequence found that it was impossible to study the diffusion of gases in water when the gas was placed above the liquid, and he was compelled to employ for his experiments a thin plate of the porous mineral hydrophane to hold up a column of water in an experimental tube, and so to provide the means of introducing the gas at the bottom of the water and of studying its upward diffusion through the water.

Hüfner explains the streaming of the dissolved gases downward through the water, which is indicated by the above experiments, by supposing that the water becomes heavier as it dissolves the gas, and sinks to the bottom.* It did not appear, however, to one of the authors that this suggestion offered a wholly satisfactory explanation of the phenomenon observed. He accordingly made a careful investigation of the phenomenon, which we shall now describe.

Method of Experiment.†

Glass tubes about 2 metres long and 18 mm. bore were employed for most of the experiments to be described.

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* Ann. Phys. Chem. (II.), Vol. lx., pp. 134-168. (1897.)

† "Unrecognised Factors in the Transmission of Gases through Water." By W. E. Adeney. Trans. Roy. Dub. Soc., p. 161, 1905. Also Phil. Mag., March, 1905.

The tubes were nearly filled either with distilled water or with sea water, and warmed and exhausted as far as desirable by means of a mercury pump. The corks closing the lower ends of the tubes were fitted with fine glass tubes to provide the means of attachment to the mercury pump for exhaustion, and for drawing off samples.

After the gases in solution and in the air spaces had been abstracted, the corks closing the upper ends of the tubes were removed, and the tubes for most of the experiments were immersed to a depth of 1,300 mm. in a large water jacket, which was kept cool by a constant flow through it of water from the main supply.

The object of the water jacket was to prevent the formation of downward convection currents, by keeping the lower portions of the water columns in the tubes at a slightly lower temperature than the upper portions, which were exposed to the temperature of the laboratory.

In most of the experiments to be described, the surfaces of the water columns were kept constantly agitated by means of currents of air drawn through their upper layers. For this purpose the tubes were fitted with corks carrying fine glass inlet and exit tubes of 0·5 mm. bore. The inlet tubes dipped at different depths from 10 to 200 mm. below the surface.

Slow currents of air were employed, at the rate of about 1,000 c.c. per hour.

When the surfaces of the water columns were left unbroken, the experimental tubes were loosely covered to protect their contents from dust.

The height of the columns of water were in nearly all the experiments about 1,800 mm. In all experiments the surfaces of the water were freely exposed to the air. Observations of barometric pressures were not thought necessary.

At the conclusion of each experiment, layers of the water of 100 to 200 mm. thick were drawn from different depths from the surface, and stored in tubes standing over mercury until they could be analysed.

The dissolved gases in these samples were extracted by boiling with a little sulphuric acid *in vacuo*. The apparatus employed for this purpose, and for the analysis of the gases, will be found described in a later part of this section.

Of the results of analysis of the dissolved gases only those from the nitrogen are given. These are expressed in c.c. at O°C., and 760 mm. bar., per litre.

The volumes of oxygen and of nitrogen which are required to saturate a litre of fresh or of salt water, when exposed to the atmosphere at different temperatures, are given in the following table, which has been drawn up by one of the authors (Letts).

TABLE 23.—Showing the Volumes of Oxygen and of Nitrogen absorbed from the Air by Distilled and by Sea Water, at a Pressure of 760 mm., and at stated Temperatures. The Volumes of Gases are expressed in c.c. per litre.

Dittmar.*					Roscoe and Lunt †	
Temperature.	Sea Water.		Distilled Water.		Distilled Water.	
°C.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.
– 5	9·42	17·85				
– 4	9·14	17·35				
3	8·89	16·37				
[illegible]	8·63	16·43				
- 1	8·40	16·00				
0	8·18	15·60	10·24	19·30		
- 1	7·97	15·21	9·97	18·86		
2	7·77	14·85	9·71	18·35		
3	7·58	14·50	9·46	17·91		

* Challenger Reports, Physics and Chemistry, Vol. I., p. 160 *et seq.*

† Journ. Chem. Soc., 1889, 552.

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DIAGRAM VII. CURVES SHOWING THE VOLUMES OF OXYGEN AND OF NITROGEN ABSORBED BY DISTILLED AND BY SALT WATERS WHEN EXPOSED AT DIFFERENT TEMPERATURES, TO THE ATMOSPHERE AT A PRESSURE OF 760 MIN., BAR.

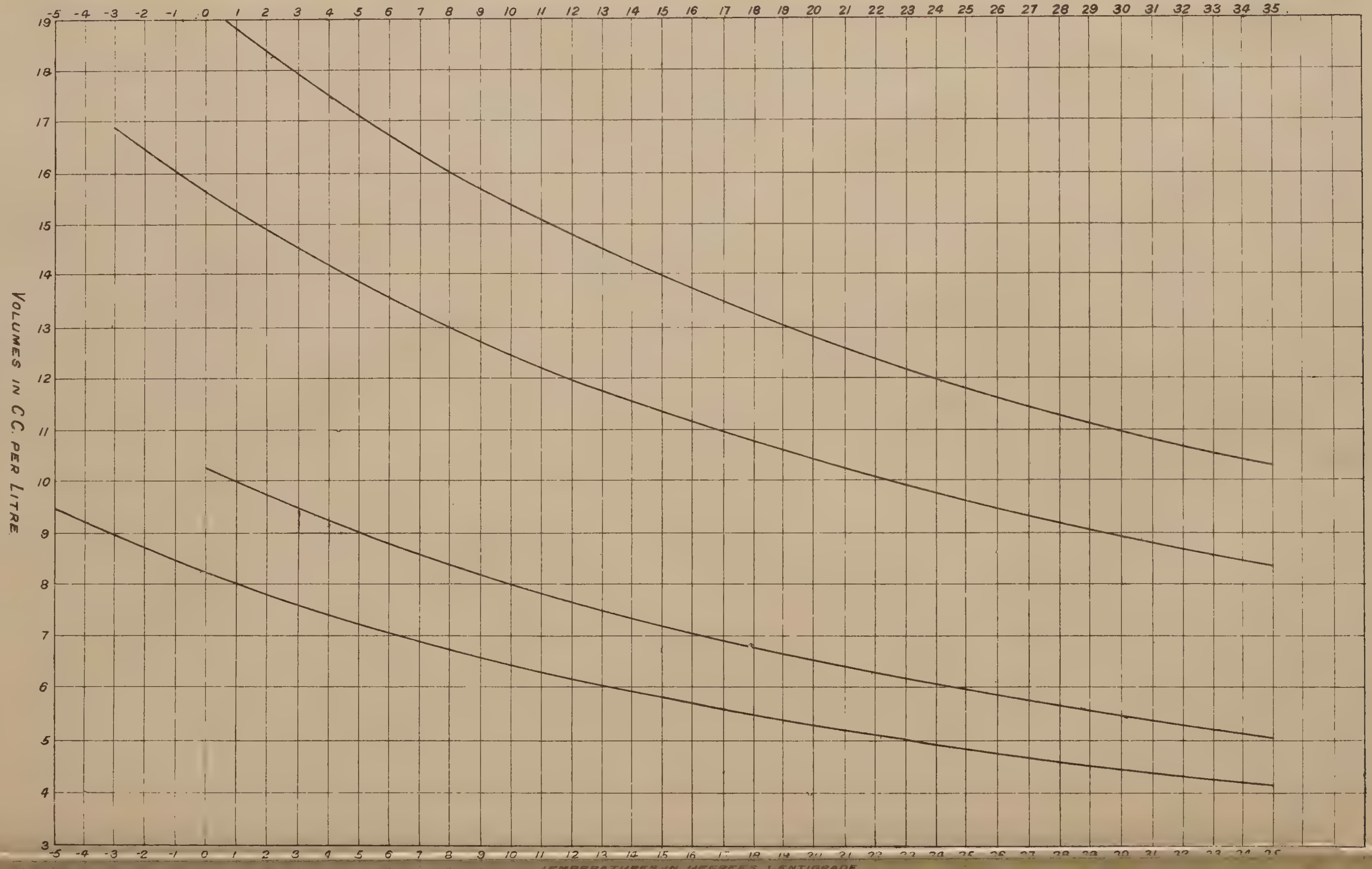

Table 23—*continued.*

	Dittmar.				Roscoe and Lunt.	
Temperature.	Sea Water.		Distilled Water.		Distilled Water.	
°C.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.
4	7·39	14·18	9·22	17·50		
5	7·22	13·86	8·99	17·09	8·68	
6	7·05	13·56	8·78	16·72	8·49	
7	6·90	13·26	8·57	16·36	8·31	
8	6·74	12·99	8·37	16·02	8·13	
9	6·59	12·73	8·18	15·69	7·95	
10	6·45	12·47	8·00	15·37	7·77 (7·87)	(15·47)
11	6·31	12·23	7·82	15·07	7·60	
12	6·19	11·99	7·66	14·77	7·44	
13	6·06	11·77	7·50	14·49	7·28	
14	5·94	11·56	7·35	14·22	7·12	
15	5·83	11·34	7·20	13·96	6·96 (7·09)	(13·83)
16	5·72	11·14	7·06	13·71	6·82	
17	5·61	10·95	6·92	13·47	6·68	
18	5·51	10·76	6·78	13·25	6·54	
19	5·41	10·58	6·66	13·01	6·40	
20	5·31	10·41	6·53	12·80	6·28 (6·44)	(12·76)
21	5·22	10·24	6·41	12·60	6·16	
22	5·13	10·07	6·30	12·39	6·04	
23	5·04	9·92	6·18	12·20	5·94	
24	4·95	9·77	6·07	12·01	5·84	
25	4·87	9·62	5·97	11·83	5·76 (5·91)	(11·78)
26	4·79	9·48	5·87	11·65	5·68	
27	4·71	9·34	5·77	11·48		
28	4·64	9·20	5·68	11·31		
29	4·55	9·07	5·58	11·15		
30	4·50	8·94	5·495	10·955		
31	4·43	8·82	5·41	10·84		
32	4·36	8·70	5·32	10·69		
33	4·30	8·58	5·24	10·55		
34	4·23	8·47	5·16	10·41		
35	4·17	8·36	5·08	10·28		

DESCRIPTION AND RESULTS OF EXPERIMENTS.

Experiments with Unbroken Surfaces.

No. 1.—Two tubes, each 1,950 mm. long and 18 mm. bore, were filled to the height of 1,800 mm. from the bottom, one with sea water and one with distilled water, both being nearly nitrogen free, and were immersed in the water jacket and kept undisturbed for twenty-eight days. The temperature of the room varied between 16·5 and 10°C., that of the jacket between 12·9 and 8·0°C. During the last week of the experiment the temperature of the room varied between 12 and 10, and that of the jacket between 9 and 8°C.

Distilled water saturated at 10°C. contains 15·37 c.c. N per litre. Sea water saturated at 10°C. contains 12·47 c.c. per litre.

Depth of layer below surface.	Sea water.	Distilled water.
1 to 200 mm.	9·24	11·50
300 to 500 mm.	8·96	11·10
800 to 1,000 mm.	8·91	8·43
1,600 to 1,800 mm.	7·89	5·84
Before aeration	1·51	1·55

No. 2.—Similar to No. 1, with the exception that the tubes were kept longer in the water jackets, viz., for 2½ months. Temperature of room at close of experiment 17·8°C., of water jacket 15·6°C.

Distilled water at 17·8°C. contains 13·29 c.c. N_2 per litre. Sea-water at 17·8°C. contains 10·80 c.c. N_2 per litre.

Depth of layer below surface.	Sea water.	Distilled water.
1 to 200 mm.	10·80	12·56
1,600 to 1,800 mm.	10·72	9·09

The foregoing results reveal a number of points of interest in connection with the streaming effect above referred to.

The most noticeable is the marked difference in rate in sea and distilled water, being much greater in the former than in the latter. Another point of interest is that the surface-layers of the sea and distilled water, in No. 1, even after exposure to the air for twenty-eight days, did not become saturated with nitrogen. Hence we may conclude that the streaming effect is more rapid in both sea and distilled water than the rate of solution at the surface exposed to the air.

These experiments, so far as they go, show that the streaming is a gravitational effect. The following experiment conclusively proves this.

No. 3.—A U-shaped tube, each limb 1,600 mm. long and 50 mm. diameter, was filled with boiling sea water and immediately closed air-tight with indiarubber corks. When the water had cooled, the tube was further exhausted by means of a mercury pump. One limb was then uncorked, and the water in it saturated with atmospheric gases by a current of air drawn through the surface-layer to a depth of 50 mm. for 48 hours. After this, a sample was drawn from the bottom of the open limb, and one from the lower portion of the closed limb, about 200 mm. from the bottom. The gases were extracted from these and the nitrogen in each determined, with the following results :—

Open Limb.	Closed Limb.
12·12	1·49

Six months later another sample was collected from the lower portion of the closed limb, as before, and the nitrogen in it determined ; it was 1·73.

Experiments with Broken Surfaces.

The Experiment No. 1, and several others which were made during the earlier part of this investigation, but which it is unnecessary here to record, since the results were similar, shows that a retardation of solution takes place at the surface of the water exposed to the air. Experiments were accordingly made in which the surfaces of the water exposed to the air were kept continuously broken.

No. 4.—A tube 1,100 mm. long and 50 mm. diameter was filled with nitrogen-free sea water, and immersed in the water jacket to a depth of 1,025 mm. A glass stirrer of a gridiron shape, 40 mm. broad, was fixed to dip 25 mm. below the surface of the water, and was mechanically rotated for 19 hours. At the end of this time the temperature of the upper layer of the water column above the water jacket was 8·3°C., and that of the water jacket 7·8°C. Samples were drawn from the top and bottom layers of the water column, and the nitrogen determined in each, with the following results :—

Top layer.	Bottom layer.
12·69	12 45
At commencement	1·51

No. 5.—A similar experiment was made with distilled water, with results as follows :—

Top layer.	Bottom layer.
13·29	11·02
At commencement	1 46

Sea-water saturated at 8·3°C. contains 12·91 c.c. N_2 per litre. Distilled water saturated at 8·3°C. contains 15·92 c.c. N_2 per litre.

In order to provide in these experiments the means of detecting whether or not the mechanical agitation of the surface-layers of the water-columns caused a circulation of the water to the bottom, a large crystal of potassium bichromate was placed at the bottom of the tubes; but in no case was the dissolved bichromate observed to rise above the immediate neighbourhood of the crystal, and become mixed with the water above it.

The results of the last two experiments proved, as was anticipated, that the downward streaming effect takes place so rapidly when the surface of the water exposed to the air is continuously agitated, that long columns of water are completely saturated with atmospheric gases with comparative rapidity.

Experiments were next made in which the surfaces of the water-column were kept broken by means of slow currents of air. It was thought that by their means it would 9e possible to make comparative observations on the effect of agitating different thicknesses of the surface-layers of two or more columns of water by the same disturbing cause.

No. 6.—Two tubes each 1,980 mm. long and 24 mm. bore, were filled with a nitrogen-free sea-water. Each tube was filled with an indiarubber cork and fine glass inlet and exit tubes of 3 mm. bore, and they were connected in series so that the same current of air could draw through the surface-layers of each column of water. The inlet-tube through which the current of air was first drawn dipped 100 mm. below the surface of the first column, and the second inlet-tube dipped 10 mm. below the surface of the second column, of water. The current of air was not previously filtered. It was continued for twenty-five hours. At conclusion temperature of room was 19·5°C., and of the jacket 15·7°C.

Sea-water saturated at 19·50°C. contains 10·50 c.c. N_2 per litre.

Depth of layer below surface.	1	2
1 to 100 mm. - -	10·57	8·01
1,500 to 1,600 mm. - -	8·91	4·08
Before aeration - - -	1·58	1·56

No. 7.—Similar to the experiment No. 6, with the exception that the inlet-tube dipped 10 mm. below the surface in the first column of water, and 100 mm. in the second column. The current of air was continued for 20 hours. Temperature of room at conclusion was 18·2°C., and of the jacket 14·9°C.

Sea-water at 18·2°C. contains 10·68 c.c. N_2 per litre.

Depth of layer below surface.	1	2
1 to 100 mm. - -	10·07	9·95
1,000 to 1,100 mm. - -	—	6·05
1,200 to 1,300 mm. - -	9·61	—
1,700 to 1,800 mm. - -	6·26	2·15
Before aeration - - -	1·61	1·56

The sea-water employed for the experiments thus far recorded was collected in Dublin Bay. It had been stored in partially full bottles for some weeks previous to use. It contained 19·57 parts chlorine per litre.

From the foregoing results it appears that the rate of aeration, as a consequence, of the streaming, was not materially affected by difference of depth of the air-inlet tubes when two water-columns were aerated in series by the same current of air. The inlet tubes dipped 100 mm. and 10 mm. below the surfaces in the columns of water 1 and 2, respectively, in Experiment No. 6, and *vice versâ* in Experiment No. 7; and yet both the columns of water which first received the air-currents in the two experiments were found to have dissolved more nitrogen than either of the second columns of water.

It appears, therefore, from these experiments that something was taken from the air by the first water column in each experiment in addition to the ordinary atmospheric gases, and that very little reached either of the second columns.

The next experiments were arranged with a view to ascertaining whether, by using slower currents of air and fine capillary glass inlet and exit tubes of 0·5 mm. bore, the streaming effect could be completely confined to the first water column.

No. 8.—Three tubes, each containing sea-water nearly nitrogen free were fitted with indiarubber corks and air inlet and exit tubes, and were connected in series, so that the same current of air could be drawn through the upper layer of each column of water to a depth of 200 mm., one after the other.

The air current was a slow one, at the rate of about 1 litre per hour. The aeration was continued for forty-eight hours and then stopped. Samples of water were then drawn from each tube as before, and stored in glass vessels standing over mercury. The nitrogen determinations are given below. The tube in which the air-current first entered was marked 1, and the one it next entered 2, and so on. The air was filtered through glass-wool.

Temperature of room - - - 12·8 to 10·0°C.
Temperature of jacket - - 8·6 to 8·3°C.

Sea-water at 10°C. contains 12·47 c.c. N_2 per litre.

Depth of layer.	1	2	3
1 to 200 mm. - - - -	12·24	11·15	11·09
800 to 1,000 mm. - - - -	8·20	2·29	2·55
1,600 to 1,800 mm. - - - -	8·13	2·18	2·54
Before aeration- - - - -	1·57	2·13	2·51

No. 9.—Similar to the Experiment No. 8, with the exception that the air-inlet tube dipped only 50 mm. below the surface. The air current was filtered through glass wool.

Temperature of room - - - 13·7 to 13·5°C.
Temperature of jacket - - 8·4 to 8·5°C.

Sea-water at 13·5°C. contains 11·67 c.c. N_2 per litre.

Depth of layer.	1	2	3
1 to 200 mm. - - - -	10·81	7·15	6·93
300 to 500 mm. - - - -	10·60	1·61	1·52
800 to 1,000 mm. - - - -	9·36	1·65	1·56
1,600 to 1,800 mm. - - - -	9·20	1·65	1·52
Before aeration - - - -	1·75	1·63	1·51

These results show that when the current of air is sufficiently washed during its passage through the surface layer of the first column of sea-water it may be passed through the surface layers of other columns of sea-water and no streaming effect occurs, although the layer of water through which the air is bubbled soon becomes saturated with atmospheric nitrogen.

It may be concluded that the streaming effect is not due to concentrated solution currents, as suggested by Hüfner, but by something in the air besides its chief gaseous constituents, and that when the something is washed out, the subsequent solution of the gases is not attended by streaming.

The sea-water employed for these experiments was also collected in Dublin Bay. It was filtered through glass wool and stored in glass bottles for a week before use It contained 19·45 grms. chlorine per litre.

Similar experiments were made with distilled water, as there were reasons for anticipating that the cause of the streaming would not be so rapidly washed out by distilled water as by sea-water.

Experiments with Distilled Water.

No. 10.—Similar to Experiment No. 8, with the exception that distilled water was used in place of sea-water.

Temperature of room - - - 11·5 to 11·8°C.
Temperature of jacket - - 8·5 to 9·0°C.

Distilled water at 11·8°C. contains 14·83 c.c. N_2 per litre.

Depth of layer below surface.	1	2	3
1 to 200 mm. - - - -	14·60	12·27	12·20
300 to 500 mm. - - - -	11·62	11·10	11·18
800 to 1,000 mm. - - - -	4·18	4·20	4·48
1,600 to 1,800 mm. - - -	3·54	3·05	3·20
Before aeration - - - -	1·55	1·73	1·97

No. 11.—Similar to No. 10, with the exception that the air current was not filtered.

Temperature of room - - - 12 to 10°C.
Temperature of jacket - - 8·7 to 8·5°C.

Distilled water saturated at 10°C. contains 15·37 c.c. N_2 per litre.

Depth of layer below surface.	1	2	3
1 to 200 mm. - - - -	13·81	12·77	12·64
300 to 500 mm. - - - -	12·20	11·17	11·08
800 to 1,000 mm. - - - -	5·20	5·17	5·14
1,600 to 1,800 mm. - - - -	4·15	4·06	4·00
Before aeration - - - -	1·75	1·55	1·51

These experiments confirm the conclusion which was drawn from the results of Experiment No. 1, viz., that the downward aeration of distilled water by the streaming effect is not so rapid as the aeration of sea-water by the same means.

They also show that the cause of the streaming was not concentrated in the first water column, as was the case with sea-water, but that, on the contrary, it equally affected the three water columns. It may be inferred from this last observation that the streaming being less in distilled water than in sea-water, is due to the something causing it being more slowly taken out of the air current by the former than the latter.

The following experiment was also made with distilled water, wide bore, 3 mm., inlet and exit tubes being employed. The inlet tube dipped 25 mm. below the surface of the water.

No. 12.—A tube 1,980 mm. long and 24 mm. bore was filled with nitrogen-free distilled water, and the air current continued for twelve hours. Temperature of room 15·5°C., of jacket 12·9°C.

Depth of layer.	—
0 to 200 - - - - -	10·56
650 to 800 - - - - -	3·9
1,500 to 1,600 - - - - -	2·68
Before aeration - - - - -	1·51

It is impossible definitely to state what is the active cause of the streaming. The author of the Paper has pointed out a possible explanation. It is that the streaming is possibly caused by minute dust particles, or by other centres of condensation, possibly of an electrical nature, carried by the air current and being taken up by the water together with the gaseous constituents of the air, and that these bring about in some way a sufficient density of the dissolved or condensed gases to render it possible for them to be drawn gravitationally downwards through water.

The fact that the streaming is more marked in sea than in distilled water may be explained by assuming that the sea-water, from the salts which it holds in solution, is able to make more use of the centres of condensation introduced by the air which is bubbled through it. When sea-water and distilled water are separately shaken up with the air, the difference of behaviour of the two waters is, as is well known, very marked, it being easy to obtain a formation of small bubbles of air in sea-water to an extent quite impossible in distilled water.

There can be no question, from the experiments recorded, that if the air be completely washed, the surface of sea-water exposed to it will become saturated with nitrogen, but no streaming effects will take place.

It is equally evident from these experiments that whatever may subsequently be discovered to be the true cause of the streaming, its effect in large volumes of sea or river water under natural conditions must be of great importance, and of such dimensions that the effect of ordinary diffusion may, in comparison, be entirely neglected.

To draw some practical conclusions from these experiments, we may take it that the aeration of de-aerated water, when protected from circulation of the surface layers to the bottom by thermal currents, requires long periods of time, extending to more than thirty days, for completion. But it is unlikely that conditions so unfavourable to re-aeration exist in nature. Circulation from the surface downwards must be set up by thermal currents to some extent in all waters exposed to daily and nightly variations of temperature, even in perfectly calm weather. But with such circulating currents the process of re-aeration of tidal waters of any decided depth, in calm weather, must at best be a slow one, and it is probably, from the long time slightly polluted waters remain partially de-aerated in calm weather, no quicker than in the experiments with long columns of water whose surfaces were kept continuously broken. These show that the average rate of transmission of nitrogen by sea water, to a depth of 6 feet, is not less than 0·15 c.c. per litre per hour, assuming that the transmission by the experimental column was uniform during the forty-eight hours they were under observation. The rate of transmission by fresh water to a similar depth is also shown to be not less than

0·06 c.c. per litre per hour. Taking the volume of oxygen transmitted as one-half that of nitrogen, we get 0·08 c.c. oxygen transmitted per litre, per hour, for sea-water, and 0·03 c.c. per litre per hour for fresh water.

If we adopt these values for sea and fresh waters, we may assume that the rates of transmission for tidal waters varies between these limits according to the proportions in which the two waters exist together in them, as follows :—

TABLE 24.

Proportion of Sea to Fresh Water.	Volumes of Oxygen transmitted, per litre, from the air in 1 hour, by de-aerated tidal waters to a depth of at least 6 feet, in calm weather.
Sea water - - - - - - - -	0·08 c.c.
3 Sea water to 1 fresh - - - - - -	0·068 c.c.
2 Sea water to 1 fresh - - - - - -	0·063 c.c.
1 Sea water to 1 fresh - - - - - -	0·055 c.c.
1 Sea water to 2 fresh - - - - - -	0·047 c.c.
1 Sea water to 3 fresh - - - - - -	0·043 c.c.
Fresh water - - - - - - - -	0·03 c.c.

This assumption is supported by a table of solubilities of atmospheric oxygen in mixtures, in different proportions, of sea and of distilled waters, which is given in the Report to the London County Council by Dr. F. Clowes and Dr. A. C. Houston, on "The Experimental Bacterial Treatment of London Sewage," 1892 to 1903, p. 225 :—

TABLE 24a.—Solubility of Atmospheric Oxygen in mixtures of sea and distilled water, in different proportions (Clowes).

Character of Water.	22–23 December, 1903. Temperature of water, 16°C.		1–2 January, 1904. Temperature of water, 13·8°C.		6–7 January, 1904. Temperature of water 14·8°C.	
	Dissolved oxygen Percentage.	Chlorine Parts per 100,000.	Dissolved oxygen Percentage.	Chlorine Parts per 100,000.	Dissolved oxygen Percentage.	Chlorine Parts per 100,000.
Distilled water - - - - - - - -	100·0	0	100·0	0	100·0	0
„ „ with 10 per cent. of sea water -	96·4	205	–	–	–	–
„ „ „ 20 „ „ -	94·0	395	93·4	402	95·9	394
„ „ „ 30 „ „ -	92·5	590	–	–	–	–
„ „ „ 40 „ „ -	90·3	780	91·3	781	91·2	772
„ „ „ 50 „ „ -	87·0	982	–	–	–	–
„ „ „ 60 „ „ -	83·6	1,163	86·8	1,169	88·1	1,161
„ „ „ 70 „ „ -	82·4	1,365	–	–	–	–
„ „ „ 80 „ „ -	80·7	1,555	83·7	1,560	84·7	1,555
„ „ „ 90 „ „ -	79·0	1,735	–	–	–	–
Sea water - - - - - - -	78·1	1,950	81·1	1,950	82·2	1,950
	–	–	–	–	14 January, 1904.	
Distilled water - - - - - -	–	–	–	–	100·0	0
„ „ with added sodium chloride. -	–	–	–	–	82·9	1,930

A proof that partially de-aerated river water very slowly re-absorbs oxygen from the air in calm weather conditions is given by the analyses recorded in the next table. Samples were collected from the surface waters of the non-tidal portion of the River Liffey, above the Weir and fully two miles below Chapelizod. The results of the analyses show that the rate of absorption of oxygen in some of the samples was not greater than

0·1 c.c., and in none did it exceed 0·3 c.c. per litre, per 24 hours, and that, notwithstanding this, the aeration of the samples at the time of collection was decidedly below saturation point.

Evidence that the re-absorption of oxygen from the air by tidal waters is also very slow will be found in Table 30, p. 77.

TABLE 25.—Analyses of Samples of Water collected from the River Liffey above the Weir at Island Bridge, Co. Dublin, illustrating the slow rate of Re-aeration of Slightly Polluted Waters in Calm Weather (Adeney).

No.	Samples.		Dissolved Gases expressed as volumes at N.T.P. per 1,000 volumes of water.			Other Constituents as parts per 100,000 of the water.					
						Nitrogen as		Organic Nitrogen in			
	Where collected.	Description.	Carbon Dioxide.	Oxygen.	Nitrogen.	Ammonia.	Nitrates.	Suspension.	Solution.	Chlorine.	Total Solids.
1	Just above the Weir, near the right bank, Sept. 21st, 1899 -	Slightly turbid, yellowish green tint; traces of suspended matter - - -	58·78	5·25	14·34	·0040	·0343	·008	·052	1·26	—
	Ditto after keeping 37 days.		62·13	0·88	14·25	·0015	·0385	—	—	—	—
2	From the bottom of the distributing tank, Sept. 21st* -	Very slightly turbid, yellowish brown tint; traces of suspended matter -	60·54	5·48	14·11	·0045	·0375	·008	·0517	1·295	—
	Ditto after keeping 38 days.		62·84	3·98	14·11	·0015	·0405	—	—	—	—
3	Just above Chapelizod, Oct. 16th -	Slightly turbid, brown colour; traces of suspended matter -	41·38	7·49	15·55	·004	·027	·023	·029	1·205	18·0
	Ditto after keeping 15 days.		42·12	6·54	15·45	·004	·035	—	—	—	—
4	Just below Chapelizod, Oct. 16th -	Similar to No. 3, but a little more turbid - -	41 01	7·63	15·52	·004	·028	·013	·045	1·26	18 0
	Ditto after keeping 17 days.		42·68	5·20	15·59	·004	·037	—	—	—	—
5	Just above the Weir, near the right bank -	Distinctly turbid, olive green tint; small quantity of vegetable debris in suspension -	43·47	5·98	15·52	·002	·026	·02	·081	1·26	18·4
	Ditto after keeping 15 days.		48·61	1·06	15·38	·035	·011	—	—	—	—
6	From bottom of distributing tank,* Oct. 24th	Slightly turbid, yellowish green tint; traces of suspended matter - - -	63·30	5·46	15·27	·0032	·040	·02	·055	1·295	—
	Ditto after keeping 9 days.		64·78	2·97	15·19	·0010	·044	—	—	—	—
7	Just above the Weir, near the right bank -	Slightly turbid, yellowish green tint; traces of suspended matter - - -	72·64	3·23	14·93	·0028	·051	·02	·079	1·4	0·0
	Ditto after keeping 8 days.		75·62	0·44	14·99	·0230	·035	—	—	—	—

The weather was dry both on September 21st and on October 16th; it had just commenced to break when Sample 6 was being collected, and heavy rain had fallen before Sample 7 was collected on the following day.

* Note the water is pumped into this tank from a point just above the Weir, where Sample No. 1 was collected, and stored there for distribution to some neighbouring institutions for outdoor and non-dietetic purposes.

PART XI.

THE MAXIMUM RATE OF ABSORPTION OF DISSOLVED OXYGEN ALLOWABLE IN TIDAL WATERS.

It is obvious that the maximum rate of absorption of oxygen which may be allowed in tidal waters must be fixed for practical purposes in accordance with the natural conditions least favourable to re-aeration, that is for calm weather, and in accordance with temperatures most favourable for absorption of oxygen by fermentation, viz., summer temperatures.

For the purpose of discussion, we may consider a tidal water in which salt and fresh waters are mixed together in equal proportions. The rate of re-aeration of such a tidal water under the conditions stated is according to the above Table 24 equal to 0·055 c.c. oxygen per litre per hour, or 0·69 c.c. per litre per 12·5 hours, which may be regarded as a complete tidal period, or again the rate is equal to 1·32 c.c. per litre per twenty-four hours. The necessary corrections for mixtures in which the salt and fresh waters exist in other proportions will not be large, and they can be made without difficulty from the data given in the table.

Any pollution which would not cause a greater rate of absorption than this, would exercise no apparent effect upon the aeration of the tidal water. We have, therefore, to enquire to what further extent may the dissolved oxygen of tidal waters be absorbed with safety to fish, and what additional temporary pollution may be allowed within this limiting condition.

From the investigations which have been made upon the effect of sewage matters on fish (*pisces*)—they have been summarised in another section of this Report*—it appears that 3 c.c., and 4 c.c., oxygen per litre, may be taken as the lowest limit to which the aeration of salt and fresh water may be respectively reduced with safety to fish at all possible temperatures. We should like, however, in doing this to emphasise by repetition the opinion we have expressed in the section referred to, p. 208.

> "That a much more extended series of investigations is necessary than any of those which we have summarised above, in order to decide the question as to what standard of dissolved oxygen should be insisted on in relation to fish life."

The air saturation value for a tidal water of the assumed composition would be 6·2 c.c. oxygen perlitre, at 18·0°C., according to the Table 23 given on p. 58, and we may take it that this may be reduced with safety to fish to 3·5 c.c. per litre. Hence we may have at this temperature an uniform and continuous absorption of dissolved oxygen at the rate of 0·055 c.c. per litre, per hour, and an additional temporary absorption of 2·7 c.c.

The period of time over which this temporary absorption should be required to be extended must vary with the conditions attending the discharge of the sewage, or of the sewage effluents, and upon the topography of the tidal river or sea border, and upon the strength and direction of the tidal currents.

Tidal waters may be roughly divided into three classes according to the favourable conditions, or otherwise, which they present for the disposal of sewage matters which may be discharged into them, as follows:—

> Class 1 may include tidal waters, the currents of which are strong enough to transport all sewage matters discharged into them, including suspended solids, and to distribute them through large volumes of water, so as enormously to dilute them before the change of tide.
>
> Class 2 may include the tidal waters, the currents of which can transport the liquid sewage matters discharged into them, and widely distribute them through large volumes of water, so as enormously to dilute them before the change of tide.
>
> Class 3 includes all other tidal waters which are not so favourably circumstanced.

The minimum period of time over which the temporary absorption of the 2·7 c.c. oxygen per litre may be extended for the first two classes of tidal waters, is six and a quarter hours if the sewage matters be discharged on the ebb tide only, or twelve and a half hours if they be discharged at all states of the tide. It must be extended over a much longer period for the third class of waters, otherwise over-pollution might easily result. The data at our disposal is insufficient to put an exact limit to the period, we can only suggest from general experience that it should be temporarily fixed at forty-eight hours. It will probably be found on investigation that it will vary for each locality. After this period, the absorption of oxygen must not exceed the rate at which re-absorption from the atmosphere will take place, viz., 0·055 c.c. per litre per hour.

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* Pollution of Water in Relation to its effect on Fish (*pisces*), p. 201.

The total absorption of oxygen allowable with the above time period of six and a quarter hours would be 3·0 c.c. per litre; with the time limit of twelve and a half hours it would be 3·4 c.c. per litre. In other words, when samples of the polluted waters in the two cases are kept out of contact with air for six and a quarter hours and twelve and a half hours respectively, their aeration may be reduced to 3·2 c.c., and 2·8 c.c., per litre, respectively.

With the time period of forty-eight hours, the total absorption allowable would be 5·3 c.c. per litre. Consequently, if a sample were kept out of contact with air for forty-eight hours, its aeration might be reduced to 0·9 c.c. per litre, but on re-aerating a portion of it, and again keeping it out of contact with air, the after rate of absorption should not exceed 0·055 c.c. per litre per hour.

The Maximum Quantities of Liquid Sewage Matters which may be mixed with Tidal Waters.

In considering this question, it must be borne in mind, as pointed out in the introduction to this section, that the aeration of a water may be reduced in three different ways by pollution; (1) by simple dilution with de-aerated waters; (2) by directly oxidizable substances; (3) by indirectly oxidizable substances.

It is well to make this distinction between the possible causes of the reduction of the aeration of a flowing water, when polluting matters are discharged into them, because they may act at very different rates.

The effect of the first is practically instantaneous, the amount of reduction it may cause can be calculated, when the volume and state of aeration of the polluting water, and of the flowing water with which it becomes mixed, are known; and these need only be approximately known to give sufficiently accurate calculations.

Directly oxidizable substances may also cause a rapid reduction of the aeration of a water, *e.g.*, ferrous sulphide.

Indirectly oxidizable substances cause, as we have found, an absorption of oxygen at a regular, and much slower rate.

A simple method for the rapid determination of oxygen absorbable by these two classes of substances will be found described in Part XIII. of this Section.

The only difference in practice when the former are present, is that the rate of absorption for the first few hours, as well as for the more extended periods of time of six and a quarter, twelve and a half and forty-eight hours, above given, must be determined. When they are not present, the rate for the more extended periods only are required to be known.

In some cases the volume of oxygen absorbed by some at least of the directly oxidizable substances can be differentiated from that absorbed by the indirectly oxidizable substances, but in most they cannot, and it is unnecessary for practical purposes to attempt to do so.

We give in the following pages descriptions of some experiments with polluted waters, in some of which only the latter class of substances, and in others both classes, were present.

1. *Rate of Absorption of Oxygen caused by Fermentative Changes only in Fresh and Salt Waters polluted by different classes of Sewage Matters.*

It may be gathered from the experiments which have been considered, and general experience confirms them, that the rate of fermentative change depends upon two main factors: (1) the quantity and character of the polluting matters in a water, and (2) the nature and state of activity of the organisms associated with them.* Thus in the experiments with distilled water and urea, Table 5, five months elapsed before any change was appreciable. Again, in the experiments with Rochelle salt, Table 2, p. 14, some eighteen days elapsed before any change was detected. When, however, both these substances were associated together, the interval which occurred before fermentation commenced could not have exceeded two or three days, since the whole of the salt was fermented in seven days, as against more than sixty days required for the complete fermentation of a similar quantity of the same substance when unassociated with any other organic substance, Table 2a, p. 15.

The experiments described in Table 9, p. 24, with Rochelle salt and asparagin also show a similarly short quiescent period before the commencement, and a similarly subsequent rapid rate of fermentation, nearly the whole of the dissolved oxygen being absorbed in twenty-four hours by the earlier steps of the fermentation (*see* Experiment 2).

The series of experiments with filtered sewage quoted on p. 28 further show that after the completion of the first stage of fermentation quite a long period of rest intervened before the second stage set in.

It is a matter of common observation that the rate of fermentation in polluted waters of the strength of ordinary sewage is so rapid that anaerobic conditions continue to obtain for several days within the mass of the water, even though it be freely exposed to the air.†

The experiments with mixtures of filtered sewage with tap water which are given in the Tables 10 and 12, pp. 28 and 29, show that in the case of the former table, when the sewage was only present in the proportion of 5 per cent., the dissolved oxygen was sufficient for the first stage of fermentation, and, further, that in 1¼ per cent. mixtures the dissolved oxygen was amply sufficient for both stages of fermentation. In the case of the latter table, mixtures of water with 2½ per cent. of sewage contained only just sufficient dissolved oxygen for the first stage, while in mixtures containing 1¼ per cent. of the same sewage the dissolved oxygen was just sufficient for both stages of fermentation.

On referring to the time occupied by the fermentation of the sewage matters in these mixtures, we find that it was considerable, so that the rate of absorption of oxygen probably did not at any time exceed the rate at which the water, when exposed to ordinary calm weather conditions, would reabsorb oxygen from the air.

Dr. McGowan in the Report already referred to, p. 322, gives the results of some suggestive and important experiments which he made to ascertain whether, when sewage was diluted sufficiently to render it conformable to the Mersey and Irwell standard for albuminoid nitrogen (0·12 part per 100,000), the mixture so obtained would, on being submitted to the incubation test, remain sweet. The mixtures contained from 3 to 12 per cent. sewage, and the results given in the succeeding table show that all but three were too strong, and that in consequence the dissolved oxygen was not sufficient for the first stage of fermentation in any but the three excepted, and one of these is doubtful, since the nitrate previously added was largely reduced during incubation, and so doubtless prevented putrefaction. It must be noted, however, that the samples of sewage were not previously filtered as in the other experiments referred to, and that they, therefore, contained colloidal and, doubtless, other suspended matters. Nevertheless, we must conclude from these experiments that it is doubtful whether screened and settled sewage, unless it be weak, can be allowed to discharge into calm tidal waters in proportions as large as 5 per cent.

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* The question of the relative rates of absorption of dissolved oxygen by sewage matters in fresh and in sea water is dealt with in the Addendum to this Section, p. 431.

† See Experiments recorded in Table 39, which give the rate of absorption of oxygen by a very strong tank liquor when kept constantly and gently shaken in contact with air.

Table 26.—Samples of Sewage sufficiently diluted to render them conformable to the Mersey and Irwell Standard of Albuminoid Ammonia, and the Mixtures so obtained submitted to the Incubation Test. (McGowan.)

Volume of sewage. c.c.	Volume of H_2O added. c.c.	Days incubated.	N_2O_5 added.	N_2O_5 & N_2O_3 after incubation.	"Oxygen absorbed" from Permanganate at 26·7°C. (80°F.) at once in—		
					Original dilution.	Portion incubated at room temperature.	Portion incubated at 26·7°C.
20	380·6*	About 8	—	—	0·20	0·37 strongly putrid	0·50 strongly putrid
25	313·0*	11	—	—	0·18	0·09 putrid	0·23 putrid
100	737*	7	—	—	0·23	0·26 ,,	0·43 very putrid
50	737*	7	—	—	0·14	0·14 ,,	0·17 sweet or doubtful
20	366*	6	—	—	0·24	0·24 just putrid	0·24 very putrid
100	944*	12	—	—	0·19	—	1·20 very putrid
100	944*	12	0·10†	—	0·19	—	1·07 very putrid
100	944*	12	0·20†	—	0·19	—	0·65 very putrid
100	944*	12	0·30†	—	0·19	—	0·92 very putrid
100	740§	6	0·30†	0·13 sweet, earthy	—	—	—
100	740§	6	0·15‡	0·13 sweet, earthy	—	—	—
25	740§	6	0·075‡	0·06 sweet	—	—	—

* Tap water. † Added in the form of potassium nitrate. ‡ Added in the form of ammonium nitrate. § Distilled water.

Note.—Two samples of tap water were examined at a later date, and were found to contain approximately 0·25 and 0·30 parts nitric nitrogen per 100,000; the tap water used above was no doubt much the same as this.

The albuminoid nitrogen in each mixture amounted to 0·12 parts, except in the last, in which it was 0·03 parts per 100,000.

Nature of Sewage employed.—For the first mixture, it was screened, and strong; for the next three, screened, and rather weak; for the fifth, it was crude, and not very strong; for the next four, it was screened and settled, soapy, but not very strong; for the last three, it was settled and rather dilute.

In the next table the results of three series of experiments by one of the authors (Letts) and his pupils are given, showing the rate of absorption of oxygen in sea water polluted by 1 per cent. of sewage previously filtered through paper:—

Table 27.—Sea Water and 1 per cent. Sewage in Stoppered Bottles at 21°C. (Letts.)*

Experiment.	Time.	(In cubic centimetres per litre at N.T.P). Dissolved Gases.				(In parts per 100,000.)					
						Unoxidised Nitrogen as			Oxidized Nitrogen as		"Oxygen Absorbed" in 4 hours at 80F.
		CO_2.	O_2.	N_2.	Total.	Free NH_3.	Albd. NH_3.	Total.	Nitrates.	Nitrites.	
1	When mixed - -	45·81	5·23	10·13	61·17	·0171	·0165	·0336	·0066	None.	·144
	After 6 hours - -	46·05	5·20	9·98	61·23	·0171	·0165	·0336	·0062	,,	·126
	,, 24 ,, - -	47·78	3·14	10·03	60·95	·0046	·0263	·0309	·0062	,,	·108
	,, 48 ,, - -	48·91	2·02	10·04	60·97	·0079	·0165	·0244	·0095	,,	·081
2	When mixed - -	46·74	5·37	10·29	62·40	·0092	·0072	·0164	·0033	None.	·091
	After 12 hours -	47·18	5·20	10·14	62·52	·0066	·0046	·0112	·0119	,,	·052
	,, 18 ,, - -	46·95	5·08	10·08	62·11	·0079	·0072	·0151	·0058	,,	·059
	,, 38 ,, - -	47·04	4·97	10·11	62·12	·0066	·0059	·0125	·0078	,,	·087
	,, 90 ,, - -	47·18	4·60	9·87	61·65	·0099	·0066	·0165	·0041	,,	·062
	,, 528 ,, - -	47·56	4·42	10·01	61·99	·0138	traces	·0138	·0062	,,	·069
3	When mixed - -	46·23	5·30?	11·49?	63·02	—	—	—	—	—	—
	After 7 days - -	47·31	4·41	11·11	62·83	—	—	—	—	—	—
	,, 14 ,, - -	47·33	3·81	10·60	61·74	—	—	—	—	—	—
	,, 21 ,, - -	47·13	3·87	11·06	62·06	—	—	—	—	—	—

* Scientific Proceedings of the Royal Dublin Society, Vol. IX. p. 333, 1900.

The most striking feature of this table is the evidence afforded of the great rapidity of the changes which occurred in the first series of experiments compared with those which took place in the second and third series. In the former about 40 per cent. of the dissolved oxygen disappeared in twenty-four hours, and 60 per cent. in forty-eight hours, whereas in the second series only about 7 per cent. had disappeared in thirty-eight hours, 14 per cent. in ninety hours, and only 18 per cent. in twenty-two days.

Owing to an accident to the gas analysis apparatus when commencing the third series of experiments, the dissolved oxygen and nitrogen in the original mixture of sewage and sea water could not be determined; but if it be assumed that the oxygen was about the same as in the preceding series, as was no doubt the case, then in seven days only 15 per cent. was lost, and at the end of twenty-one days 26 per cent.

The composition of the sewage employed is, no doubt, mainly responsible for this remarkable difference in the behaviour of the mixtures, No. 1 sample being evidently much stronger in carbon-oxidisable substances than the other two.

As regards the inorganic nitrogen determinations, it is impossible to draw any definite conclusion from them, owing to the smallness of the quantities involved and to the large errors attending even the best methods for their determination.

On the whole, it may be inferred from these experiments that ordinary liquid sewage may be mixed with sea water in proportion of 1 per cent. without danger of lowering the aeration of the latter to any serious extent, so far as the fermentative changes which they would undergo are concerned.

Some experiments have quite recently been made by one of the authors (Adeney) to determine the rate of fermentation in fresh and in sea water, when polluted by varying proportions of septic tank liquor. The succeeding table gives the results of experiments with a sample of liquor collected from the experimental tank at the Belfast Sewage Works on March 2, 1905.

TABLE 28.—Analyses showing the Course and Rate of Fermentative Changes, under Aerobic Conditions, of the Polluting Matters in a Sample of Septic Tank Liquor collected March 2, 1905, from the Experimental Sewage Works at Belfast. (Adeney.)

The following experiments were made with this sample:—

(1) A mixture was made of 1 part of the sample (unfiltered) and 9 parts of tap water, aërated and immediately analysed.
(2) A portion of the mixture was kept 3 days out of contact with the air and then analysed.
(3) Another portion was kept 4 days out of contact with the air and analysed.
(4) Another portion of known volume was enclosed in a well-stoppered bottle together with a known volume of air, and was kept for 40 days; both air and liquid were then analysed.
(5) Another portion was similarly enclosed and kept 6 months, when both air and liquid were then analysed.
(1a) A mixture was made of 1 part of the fresh sample with 19 parts of tap-water, aërated and immediately analysed.
(2a) A portion of this mixture was kept for 3 days out of contact with the air and then analysed.
(3a) Another portion was kept for 12 days out of contact with the air and then analysed.
(4a) Another portion, of known volume, was enclosed with a known volume of air in a well-stoppered bottle and kept for 6 months, when both air and liquid were analysed.

The bottles were immersed during the time of keeping neck downwards in distilled water, and kept at the temperature of the laboratory.

Exp.	Gaseous constituents expressed as volumes at 0°C., and 760 mm. Bar., per 1,000 volumes of water.									Other constituents expressed as parts by weight per 100,000 parts of water.			
	Dissolved gases.			Atmosphere in bottles.						Nitrogen as—			
				After fermentation.			Before fermentation.						
	Carbon dioxide.	Oxygen.	Nitrogen.	Carbon dioxide.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.		Organic.	Ammonia.	Nitrites.	Nitrates.
1	12·01	7·38	15·25	—	—	—	—	—		0·16	0·25	0·0	0·0
2	18·71	1·70	15·30	—	—	—	—	—		0·12	0·3	0·0	0·0
3	19·64	0·72	15·22	—	—	—	—	—		0·12	0·3	0·0	0·0
4	20·20	5·72	13·90	8·22	100·74	487·5	127·85	480·95		0·05	0·0	0·0	0·25
5	19·86	6·35	15·04	9·3	111·00	535·0	140·36	528·04		0·07	0·0	0·0	0·25
1a	8·08	7·40	15·37	—	—	—	—	—		0·10	0.13	0·0	0·01
2a	10·51	5·24	15·40	—	—	—	—	—		0·10	0·15	0·0	0·01
3a	12·26	3·65	15·33	—	—	—	—	—		0·10	0·15	0·0	0·01
4a	13·34	6·17	14·05	2·66	44·92	235·5	61·24	230·36		0·08	0·0	0·0	0·28

TOTAL QUANTITIES OF OXYGEN ABSORBED, AND OF PRODUCTS FORMED DURING EACH EXPERIMENT :—

Exp.	Oxygen absorbed.	Carbon dioxide formed.	PRODUCTS—		
			Ammonia.	Nitrites.	Nitrates.
2	5·68	6·70	0·05	0·0	0·0
3	6·66	7·63	0·05	0·0	0·0
4	28·77	16·41	—	—	0·25
5	30·39	17·11	—	—	0·25
2a	2·16	2·43	0·02	0·0	0·0
3a	3·75	4·16	0·02	0·0	0·0
4a	17·53	7·92	—	—	0·20

For the first five experiments in this table, mixtures of tap water with 10 per cent. of the sample of tank liquor, unfiltered, were employed.

In Experiments 2 and 3 portions of this mixture were kept entirely out of contact with the air, and they show that 5·68 and 6·66 c.c. dissolved oxygen, per litre, were absorbed in three and four days, respectively.

Portions of the same mixture were enclosed, in Experiments 4 and 5, in well-stoppered bottles, each with an excess of air, and were kept for forty days and six months, respectively. The volumes of oxygen absorbed during these periods were 28·77 and 30·39 c.c. per litre, respectively.

Experiments 2a and 3a were made with mixtures of tap water with 5 per cent. of the unfiltered sample. The portions of the mixture employed for them were kept three and twelve days, respectively, out of contact with the air. The volumes of dissolved oxygen which were absorbed were, respectively, 2·16 and 3·75 c.c. per litre. In Experiment 4a. a portion was enclosed with an excess of air and kept for six months. The results show that 17·53 c.c. oxygen per litre were absorbed, and that the fermentative changes were complete.

On comparing the results of Experiment 2 with those of Experiment 2a, the retarding influence of dilution on the rate of fermentation is seen. The mixtures in the two cases were kept for similar periods of time, and were otherwise similar in all respects except in that of strength. The results show that in the stronger mixture 5·68 c.c. oxygen per litre were absorbed, and that in the weaker mixture, just half the strength, less than half the volume of oxygen, 2·15 c.c., were absorbed.

The volume of oxygen required for the complete fermentation of the sewage matters in the two mixtures are shown by the results of the Experiments 4 and 4a. These on being multiplied, each by its dilution factor, yield 287·7 c.c. and 350·6, respectively, per litre. The quantities of carbon dioxide and of nitrates formed in the two cases were 171·1 c.c. and 0·25 parts nitrogen as nitrates, and 158·4 c.c carbon dioxide and 0·4 parts nitrogen as nitrates, per litre and per 100,000 parts, of the mixture, respectively.

It appears from these experiments that septic tank liquor of the strength of the sample employed could be discharged into calm river waters in the proportion of 10 *per cent., without danger to their aeration.*

A series of experiments with a second and stronger sample of unfiltered Belfast tank liquor and sea water, by the same author, are given in the following table :—

TABLE 29.—ANALYSIS showing the Course and Rate of Fermentative Changes, under Aerobic Conditions of the Polluting Matters in a sample of Septic Tank Liquor, collected 1.0 p.m., March 9th, 1905, from the Experimental Septic Tank at the Belfast Sewage Works. (Adeney.)

The following experiments were made with this sample :—

(1) A mixture was made of 1 part of the fresh sample (unfiltered) and 4 parts of sea water, aerated, and immediately analysed.
(2) A portion of the mixture was kept 24 hours out of contact with air, and then analysed.
(3) Another portion of the mixture of known volume enclosed with a known volume of air in a well-stoppered bottle, and kept for 4 months, both liquid and air were then analysed.
(4) Another portion was similarly enclosed and kept 6 months, when both liquid and air were analysed.
(1a) A mixture was also made of 1 part of the fresh sample (unfiltered) and 9 parts of sea water, and immediately analysed.
(2a) A portion of the mixture was kept out of contact with air for 26 hours, and then analysed.
(3a) Another portion of the mixture of known volume enclosed with a known volume of air in a well-stoppered bottle, and kept 4 months and analysed.
(4a) Another portion was similarly enclosed and kept for 6 months, and then analysed.
(1b) A part of the fresh sample was passed through an experimental gravel filter, and the effluent obtained was analysed without delay.
(2b) A portion of the effluent was enclosed with a known volume of air in a stoppered bottle and kept for 25 days, and was then analysed.
(3b) Another portion of the effluent similarly enclosed and kept for 60 days.
(1c) A part of the fresh sample was more quickly passed through the same filter, and the effluent was immediately analysed.
(2c) A portion of this effluent was enclosed with a known volume of air, and kept for 21 days, when both effluent and air were analysed.
(3c) Another portion of the same effluent similarly enclosed, and analysed after being kept for 6 months.

The bottles were kept neck downwards in distilled water at the temperature of the laboratory.

Exp.	Gaseous constituents expressed as volumes at 0°C., and 760 mm. Bar., per 1,000 volumes of water.								Other constituents expressed as parts by weight per 100,000 parts of water.			
	Dissolved gases.			Atmosphere in bottles.					Nitrogen as—			
				After fermentation.			Before fermentation.					
	Carbon dioxide.	Oxygen.	Nitrogen.	Carbon dioxide.	Oxygen.	Nitrogen	Oxygen.	Nitrogen.	Organic.	Ammonia.	Nitrites.	Nitrates.
1	52·55	5·82	12·04	—	—	—	—	—	0·2	0·68	0·0	0·01
2	58·55	0·19	12·04	—	—	—	—	—	0·2	0·7	0·0	0·01
3	72·59	2·54	10·72	25·68	57·14	514·9	135·51	509·78	0·12	0·05	0·0	0·65
4	80·37	1·97	12·72	17·15	27·90	412·7	108·36	407·64	0·12	0·0	0·0	0·69
1a	48·78	5·63	11·67	—	—	—	—	—	0·15	0·34	0·0	0·02
2a	54·61	0·06	11·69	—	—	—	—	—	0·13	0·36	0·0	0·02
3a	56·22	4·64	12·72	11·45	86·56	471·6	124·85	469·65	0·08	0·0	0·0	0·36
4a	59·12	4·24	12·45	10·0	68·05	429·15	113·27	426·11	0·05	0·0	0·0	0·35
1b	169·23	5·97	13·73	—	—	—	—	—	0·2	2·5	trace	0·0
2b.	181·56	0·0	14·08	12·52	0·0	267·1	70·14	263·86	0·1	0·4	0·7	0·9
3b	185·3	0·0	13·95	8·0	0·0	223·2	59·22	222·78	0·1	0·7	0·1	1·5
1c	156·33	6·02	13·69	—	—	—	—	—	0·18	1·5	0·0	0·0
2c	183·85	0·87	13·26	24·18	14·20	429·0	112·66	423·83	0·12	0·0	0·0	1·2
3c	179·54	1·17	16·00	22·55	12·6	446·1	117·7	442·8	0·15	0·0	0·0	1·2

TABLE 29—*continued.*

TOTAL QUANTITIES OF OXYGEN ABSORBED, AND OF PRODUCTS FORMED DURING EACH EXPERIMENT.

Exp.	Oxygen absorbed.	Carbon dioxide formed.	Products.		
			Ammonia.	Nitrites.	Nitrates.
2	5·63	6·00	0·02	0·0	0·0
3	81·65	45·72	–	–	0·64
4	84·31	44·97	–	0·0	0·68
2a	5·57	5·83	0·02	0·0	0·0
3a	39·28	18·89	–	–	0·34
4a	46·41	20·34	–	–	0·33
2b	76·11	24·85	0·0	0·7	0·9
3b	65·19	24·07	0·0	0·1	1·5
2c	103·61	51·70	0·0	0·0	1·2
3c	149·91	45·76	0·0	0·0	1·2

Experiments 1 and 2 show that in a 20 per cent. mixture, 5·63 c.c. dissolved oxygen per litre were absorbed in 24 hours. Experiment 3 gives 81·65 c.c. oxygen as the volume absorbed per litre in 4 months, and Experiment 4, 84·31 c.c. as the volume taken up in 6 months.

Experiments 1a to 4a were made with a 10 per cent. mixture. They show that 5·57 c.c. oxygen per litre were absorbed in 26 hours, 39·28 c.c. in 4 months, and 46·41 c.c. in 6 months.

On comparing the results of Experiments 2 and 2a together, we find that when sewage is mixed in comparatively large proportions with water the retarding influence of dilution on the rate of absorption of oxygen is not discernible, as is the case when the sewage is present in smaller proportions. The two experiments referred to were similar in every respect, with the exception that the former contained 20 per cent. of tank liquor, and the latter 10 per cent., but the rate of absorption in the two cases was practically identical.

These experiments prove that septic tank liquors of the strength of the sample employed could not be discharged into sea water in the proportion of 10 *per cent. within the limits of safety to the aeration of the same.*

The other experiments recorded in this table illustrate another point in fermentation, which has already been dealt with (*see* p. 27).

Dr. Fowler has recorded a large number of determinations of the rate of absorption of dissolved oxygen in known mixtures of thoroughly aerated tap-water and of filtrates from one of the bacteria beds, treated with septic tank liquor, at the Manchester Sewage Purification Works. The determinations were carried out as follows:—One volume (generally 120 c.c.) of the filtrate was mixed with 9 volumes (1,080 c.c.) of tap water, which had been thoroughly shaken with air. After standing for a short time to allow any bubbles of air to escape, the dissolved oxygen was determined in about 400 c.c. of this mixture by means of the Thresh method; 600 c.c. of the remaining liquid was then incubated at 27·7°C. for two days, and the dissolved oxygen again determined. The results obtained for the year 1901 are given in the next table. Mixtures of 62 different samples of filtrate with tap-water were examined during the year. The dissolved oxygen in 11 of them was completely absorbed during the 48 hours' incubation. The average absorption for the remaining mixtures amounted to 3·5 c.c. per litre per 48 hours, the maximum absorption being 6·1 c.c., and the minimum 1·5 c.c. per litre, per 48 hours.

It will be seen that these volumes are generally well under the maximum, which was above taken as allowable for absorption in 48 hours, viz., 5·6 c.c. per litre; and it must be remembered that the mixtures in these experiments were kept at a temperature much more favourable for rapid fermentation than those which ordinarily obtain under atmospheric conditions. We may therefore conclude that filtrates from single contact beds, such as those employed in these experiments, may be safely discharged into tidal waters in proportions certainly larger than 10 per cent., and probably as large as 20 per cent.

Dr. Fowler has also recorded the results of similar experiments which were carried out in the succeeding year, 1902, and they completely confirm this conclusion.

TABLE 29A.—Experiments showing the Rate of Absorption of Dissolved Oxygen in Tap-water polluted by 10 per cent. Filtrate from one of the Bacteria Beds, treated with Septic Tank Liquor, at the Manchester Sewage Purification Works. (Fowler.)*

The Dissolved Oxygen determinations are expressed in c.c. at N.T.P. per 1,000 c.c. of water, the other determinations in parts per 100,000.

Date.	Oxygen absorbed. 4 hours.†	Incubator Test.† 3 minutes—Oxygen absorbed.		Nitrate.†	Dissolved Oxygen.		Reduction of Dissolved Oxygen.
		Before.	After.		At once.	After 2 days' incubation.	
1901–2.							
Dec. 27	1·67	·84	·76	·67	7·1	3·6	3·5
„ 30	1·57	·76	·60	·76	7·2	4·1	3·1
1902–3.							
Jan. 11	2·30	1·26	1·07	·70	6·8	4·6	2·2
„ 13	2·63	1·41	1·09	·76	7·1	4·9	2·2
Feb. 17	3·83	2·63	1·83	·59	7·7	5·9	1·8
„ 18	3·44	2·24	1·96	·41	7·7	5·1	2·6
„ 25	1·93	·86	·61	·89	7·6	5·8	1·8
„ 28	4·24	2·74	2·29	·36	7·6	4·4	3·2
Mar. 1	3·11	2·17	1·80	·37	7·0	4·6	2·4
„ 3	2·90	1·99	2·00	·66	6·6	3·7	2·9
„ 7	4·61	2·90	3·39	·32	7·1	1·2	5·9
„ 19	3·34	2·17	1·31	1·42	6·6	3·8	2·8
„ 22	5·00	2·59	2·86	·46	7·1	3·3	3·8
„ 24	3·31	1·73	1·60	·82	6·8	4·4	2·4
April 1	2·59	1·61	1·60	·34	6·9	3·0	3·9
„ 4	2·89	1·60	1·56	·29	7·0	3·1	3·9
„ 5	2·46	1·14	1·09	·42	7·7	4·3	3·4
„ 12	3·73	2·59	2·77‡	·05	7·7	2·5	5·2
„ 14	2·79	1·51	1·51	·50	6·6	3·2	3·4
„ 19	3·36	1·80	1·64	·16	6·8	2·9	3·9
„ 22	2·87	1·39	·12	·90	6·9	2·7	4·2
„ 23	3·37	1·61	1·76	·26	6·7	3·5	3·2
„ 26	2·74	1·74	1·57	·19	6·7	3·6	3·1
„ 29	3·13	2·06	1·91	·11	6·5	1·5	5·0
May 3	3·00	1·63	·80	·84	6·7	3·7	3·0
	1·97	·91	·80	·61	7·2	4·7	2·5
„ 5	1·77	·86	·46	1·31	6·9	3·9	3·0
	3·00	1·57	1·23	·63	7·0	3·9	3·1
„ 6	2·77	1·46	1·26	·39	6·7	2·8	3·9
	3·69	1·80	2·03‡	0	7·0	2·9	4·1
„ 10	2·69	1·69	1·43	·26	6·3	0	6·3
„ 12	2·00	1·00	·86	·70	6·8	3·1	3·7

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* Annual Report of the Rivers Department of the City of Manchester for the year ending March 25th, 1903, Table 22.

† These tests were made with the undiluted filtrate.

‡ Samples thus marked were putrescent after incubation all the other samples remained sweet.

TABLE 29A—*continued.*

Date.	Oxygen absorbed. 4 hours.†	Incubator Test.† 3 minutes—Oxygen absorbed.		Nitrate.†	Dissolved Oxygen.		Reduction of Dissolved Oxygen.
		Before.	After.		At once.	After 2 days' incubation.	
May 12	3·36	1·83	1·91	·51	6·6	0·5	6·1
,, 13	3·26	1·63	2·26	·30	6·4	0	6·4
	5·20	3·29	4·34‡	0	6·7	0	6·7
,, 31	3·91	2·17	3·20‡	·11	6·2	0	6·2
	3·54	1·97	2·89‡	·06	6·3	0	6·3
June 2	3·03	1·54	1·54	·16	6·1	0	6·1
	4·54	2·57	2·83‡	·06	6·4	0	6·4
,, 3	4·71	1·69	3·80‡	·06	6·0	0	6·0
Oct. 11	2·91	1·60	1·59	·48	6·1	3·3	2·8
,, 13	2·94	1·67	1·16	·49	6·3	3·4	2·9
,, 14	1·71	·93	·81	·34	6·2	2·9	3·3
,, 18	2·13	1·09	·80	·51	6·7	3·0	3·7
,, 20	1·89	·91	·70	·60	6·3	4·1	2·2
,, 21	2·97	1·61	1·36	·25	6·8	0	6·8
,, 25	2·41	1·27	1·04	·58	6·4	3·9	2·5
,, 27	1·94	1·29	·77	·96	6·3	0	6·3
Nov. 8	3·09	1·87	1·77	·33	6·2	1·4	4·8
,, 10	2·01	·93	·84	·64	6·2	3·0	3·2
,, 11	2·97	1·64	1·37	·51	6·4	2·1	4·3
,, 18	2·60	1·47	1·41	·77	6·8	0·8	6·0
Dec. 1	2·57	1·29	·89	·74	7·0	4·6	2·4
,, 2	1·51	·66	·56	·93	7·0	5·5	1·5
,, 3	2·17	1·17	·94	·73	7·1	4·5	2·6
,, 6	3·89	2·50	1·30	·37	7·2	3·8	3·4
,, 8	4·27	2·81	2·67	·51	7·2	3·4	3·8
,, 13	4·30	2·49	2·61‡	·21	6·9	2·9	4·0
,, 15	3·76	1·96	1·60	·90	7·0	2·7	4·3
,, 16	2·39	1·39	·79	·84	7·0	3·8	3·2
,, 27	2·60	1·44	1·41	·33	7·0	0·9	6·1
,, 30	3·07	1·69	1·63	·47	6·9	0	6·9

† These tests were made with the undiluted filtrate.
‡ Samples thus marked were putrescent after incubation ; all the other samples remained sweet.

A number of experiments are given in the succeeding table which give the rates of absorption of oxygen by fermentative changes in samples of tidal water polluted by fresh sewage matters.

The samples were collected from the lower portion of the estuary of the River Liffey and immediately below the Rathmines and Pembroke main drainage outfall. The discharge of sewage from this outfall is limited to the first five hours of the ebb tide.*

The percentage of sewage matters in the samples have been calculated from the quantities of ammonia in them, taking the sewage as discharged from the outfall to be—from the analyses which are given of it—less than half the strength of most town sewages.

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* The sewage from the outfall is largely mixed with subsoil water, which contains considerable quantities of nitrates Hence it is not discharged in a state of putrefaction.

TABLE 30.—Analyses showing the Rate of Absorption of Dissolved Oxygen, by Fermentative Changes, in Tidal Waters polluted by Sewage Matters. The Samples were collected from the Estuary of the River Liffey during the ebb tide, just below the Rathmines and Pembroke main drainage outfall, in calm weather. The Sewage from this Outfall is only discharged during the first five hours of the ebb tide. Gaseous constituents expressed as volumes at 0°C., and 760 mm. Bar., per 1,000 volumes, and other constituents as parts by weight per 100,000 parts of water. (Adeney.)

No.	Temp. °C.	Time kept.*	Carbon dioxide.	Oxygen.	Nitrogen.	Oxygen at time of collection.	Calculated rate of absorption per 48 hours.	Nitrogen as Ammonia	Chlorine.	Approximate % of sewage present in waters.†	State of weather.
1	7	4 hrs.	85·05	5·27	15·31	5·30	·36	·16	837	4	Calm and dry.
2	9	4 „	87·40	4·77	15·20	5·42	7·60	·60	665	15	Calm and wet.
3	8	6 „	63·20	5·95	14·47	6·00	0·40	·042	1295	1	Calm and dry.
4	8	23 „	83·98	2·16	15·31	5·13	5·94	·44	999	11	Calm and frosty.
5	10	23 „	64·08	6·03	13·62	6·53	1·0	·175	1365	4·5	Stormy and wet.
6	8	26 „	55·83	5·62	13·28	5·85	0·46	·05	1890	1·25	Calm and dry.
7	8	31 „	60·96	5·77	14·48	6·00	·36	·042	1318	1	Calm and dry.
8	8	48 „	62·74	3·80	14·26	5·89	2·09	·16	1453	4	Calm and frosty.
9	8	7 days	61·74	4·80	14·26	5·90	·32	·032	1348	0·75	Calm and dry.

Analyses of average samples of sewage hourly collected from the bottom of the Penstock Chamber, from half an hour after the gates were opened to half an hour after they were closed.

No.	1905.	High water.	Nitrogen as		Chlorine.	Solids in solution.	Solids in suspension		Remarks
			Ammonia.	Nitrates and Nitrites.			Mineral.	Volatile.	
1	April 4	10.58 a.m.	2·0	·05	179	383	4·25	10·20	Weather fine.
2	„ 5	11.27 a.m.	2·5	·06	173	384	3·3	9·3	„ „
3	„ 6	11.57 a.m.	2·1	·10	157	347	2·6	7·4	„ „
4	„ 18	9.56 a.m.	1·4	·10	134	327	40·5	32·3	Showery.
5	„ 19	10.39 a.m.	2·5	·13	173	387	2·5	3·5	Wet.
6	„ 20	11.25 a.m.	1·8	·13	170	380	10·0	11·0	Fine.
7	„ 21	12.0 p.m.	1·6	·10	144	326	3·6	6·4	Fine.
	Average - - -		2·0	·095	161	362	12·4	11·4	

As might be anticipated from the variable composition and fermentative characters of sewage, the results of these experiments prove that an exact relationship cannot be drawn between the rates of absorption of dissolved oxygen, and the percentage of sewage matters present in a polluted water. Nevertheless, the results bear out those of the preceding experiment in showing that the dissolved oxygen in unpolluted tidal waters is in danger of being completely absorbed in forty-eight hours, if mixed with a greater proportion than from 5 to 10 per cent. of ordinary liquid sewage matters.

Summary of Results of Experiments on the Rate of Absorption of Dissolved Oxygen by Fermentative Changes in slightly Polluted Waters under Aerobic Conditions.

We give in the following table a summary of the results of the experiments which we have quoted on this question of the maximum proportions of different classes of sewage matters allowable in fresh and salt water :—

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* The bottles in which the samples were collected were completely filled and carefully corked and their contents were kept out of contact with the air during the time stated in this column.

† The figures in this column are calculated from the quantities of ammonia in the sample, and from the average quantity in the sewage as discharged from the above-mentioned outfall. The average composition of the sewage is given in the succeeding table. The analyses show that the sewage is very dilute, less than half the strength of the sewage employed in previous experiments. Hence twice the quantity of ammonia has been taken for calculating the percentages of sewage in the waters.

Table 31.—Summary of the Results of the Experiments on the Rates of Absorption of Dissolved Oxygen in Fresh and in Salt Waters, polluted by known, or approximately known, quantities of different classes of Sewage Matters.

No.	Description of water.	Description and percentage of polluting matters.	Volume of oxygen absorbed, in c.c. at 0°C., and 760 mm. bar., per litre in 48 hours.	Temp. C.	Strength of sewage employed in experiments, in terms of volumes of oxygen absorbed during complete fermentation.	
					First Stage.	Second Stage.
1	Tap water - -	Sewage[1]; 2½ % -	0·21*	15 to 20	132	174
2	Tap water - -	Septic tank liquor[2]; 5 % - - -	1·44	10 to 14	224	80
3	Tap water - -	Septic tank liquor[2]; 10 % - - -	3·8	10 to 14	224	80
4	Tap water - -	Effluent from filter bed[3]; 6¼ % - -	0·2*	15 to 20	0	48·8
5	R. Mersey, just before junction with Manchester Ship Canal[4]	Polluting matters = to about 6 % septic tank liquor (first stage) - - -	0·75	12 to 15	18·3	19·2†
6	Manchester Ship Canal, just before junction with R. Mersey[5]	Polluting matters = to about 17 % septic tank liquor (first stage) - - -	3·3	12 to 15	36·8‡	29·8†
7	Sea water - -	Sewage[6]; 1 % - -	3 21	21	—	—
8	Sea water - - -	Ditto - - -	0·44	21	—	—
9	Sea water - - -	Ditto - - -	0·22	21	—	—
10	Tidal river water -	Sewage[7]; 4 % - -	0·36	7 to 12	—	—
11	Tidal river water -	Sewage[7]; 15 %- -	7·60	9 to 12	—	—
12	Tidal river water -	Sewage[7]; 11 %- -	5·94	8 to 12	—	—
13	Tidal river water -	Sewage[7]; 4½ %- -	1·0	10 to 12	—	—
14	Tidal river water -	Sewage[7]; 4 % - -	2·09	8 to 12	—	—
15	Tidal river water -	Sewage[7]; 1 % - -	0·4	8 to 12	—	—
16	Tidal river water -	Sewage[7]; 1¼ % -	0·46	8 to 12	—	—
17	Tidal river water -	Sewage[7]; 1 % - -	0·36	7 to 12	—	—
18	Tidal river water -	Sewage[7]; ¾ % - -	0·32	9 to 12	—	—
19	Sea water - - -	Septic tank liquor[8]; 20 % - - -	11·26	10 to 14	312·5	109†
20	Sea water - - -	Septic tank liquor[8]; 10 % - - -	11·14	10 to 14	312·5	109†
21	Tap water - -	Filtrate from contact bed[9]; 10 % 51 samples:—				
		Max. - -	6·1	27·7	—	—
		Mean - -	3·5		—	—
		Min. - - -	1·5		—	—

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[1] Table 10. [2] Table 28. [3] Table 14. [4] Table 34. [5] Table 35. [6] Table 27. [7] Table 30. [8] Table 29. [9] Table 29A.

* Note these figures are based on the assumption that the rate of absorption of oxygen was uniform during the time the mixtures were kept, 32 and 30 days, respectively, and they are therefore certainly too low.

† The volume of oxygen absorbed during the second stage of fermentation has been calculated from the equation given on p. 44.

‡ A portion of this volume of oxygen, 7·28, was taken up for the oxidation of 4·16 c.c. sulphuretted hydrogen.

2. *Rate of Absorption of Oxygen by Fermentative Changes in Effluents from Filter Beds and from Land Treatment.*

Mr. F. Scudder communicated in his evidence before the Royal Commission on Sewage Disposal, the results of a valuable series of analyses of effluents as discharged into various rivers under the jurisdiction of the Mersey and Irwell Joint Committee. They include not only the ordinary analytical determinations, but also the results obtained by the incubation test, and the rate of absorption of dissolved oxygen in each effluent, after aeration, during twenty-four and forty-eight hours. They are quoted in the two succeeding tables.

On reference to them it will be found that in thirty-one of the effluents from land treatment, or from filter beds, the rate of absorption during the forty-eight hours did not exceed the rate of absorption of atmospheric oxygen by fresh water under calm-weather conditions; and in the majority of the remaining effluents the absorption of oxygen in forty-eight hours did not exceed 4·4 c.c. per litre, which is the maximum amount that may be absorbed from fresh water according to the limit we have adopted in this discussion.

It is evident, therefore, that the state of aeration of the greater number of these effluents must be regarded as of even more importance from the point of view of pollution, than the quantity of the fermentative matters which they contained. Thus any one of the thirty-one effluents above referred to, if wholly de-aerated, when mixed with an equal volume of tidal water, would reduce the aeration of the latter by one-half by simple dilution, but would not otherwise appreciably affect it.

TABLE 32.—Analyses of Sewage Effluents from Sanitary Authorities in the Mersey and Irwell Watershed, made during the months of August and September, 1900 (Scudder).

Chemical Results expressed in Grains per Gallon ; Dissolved Oxygen in cc. per Litre.

No.	Authority.	Ammonia.		Oxygen absorbed.		Chlor-ine.	Nitrates and Nitrites.	Dissolved Oxygen Test.				Method of Purification.	Remarks on Sample as received.
		Free.	Albu-minoid.	3 mins.	4 hours.			At start.	After 24 hours.	After 48 hours.	Cc. consumed		
1	Little Lever U.D.C. - - -	0·173	0·044	0·08	0·09	7·5	1·21	—	—	—	—	Tanks and filters	Clear, colourless. No smell.
2	Crompton U.D.C. - - -	0·28	0·022	0·08	0·16	2·3	0·39	6·8	6·2	5·8	1·0	Tank and filter -	Clear, colourless. No smell.
3	Cheadle and Gatley U.D.C. -	0·42	0·022	0·10	0·27	3·1	0·30	6·5	6·4	6·2	0·3	Tanks and filters	Clear, colourless. No smell.
4	Westhoughton U.D.C. (Marsh Brook) - - - - -	0·31	0·038	0·13	0·31	3·5	0·12	7·8	7·0	7·0	0·8	Land treatment -	Clear, colourless, trace of brown sediment. No smell.
5	Hayfield R.D.C. - - - -	0·42	0·042	0·15	0·32	3·0	0·11	6·8	6·6	5·4	1·4	Tanks and land -	Faint brown colour, trace of brown sediment. Very faint smell.
6	Romiley U.D.C. - - - -	0·45	0·054	0·16	0·32	4·5	0·44	6·4	6·4	5·8	0·6*	Bacteria beds -	Clear, colourless. No smell.
7	Hollingworth U.D.C. - - -	0·77	0·067	0·13	0·33	3·5	0·10	6·6	5·7	5·6	1·0	Tanks and filters	Faint brown colour, traces of brown sediment. No smell.
8	Littleborough U.D.C. - - -	0·98	0·073	0·18	0·34	4·8	0·03	6·8	6·0	5·2	1·6	Tanks and filters	Clear, colourless. No smell.
9	Ashton-on-Mersey U.D.C. - -	0·45	0·039	0·17	0·35	4·1	0·14	7·7	7·4	6·6	1·1	Tanks and land -	Clear, colourless, trace of brown sediment. No smell.
10	Wilmslow U.D.C. (N. Outfall) -	0·59	0·033	0·19	0·38	3·5	0·10	7·0	6·9	6·7	0·3	Tanks and land -	Slightly turbid, no sediment. Faint soapy smell.
11	Bucklow (Timperley) R.D.C. -	0·63	0·084	0·16	0·38	—	0·04	6·7	5·6	5·4	1·3	Tanks and filters	Slightly turbid, brown sediment. No smell.
12	Mossley Corporation - - -	1·12	0·096	0·14	0·38	—	—	6·5	6·0	5·7	0·8	Tanks and filters	Light brown, with brown sediment. Faint earthy smell.
13	Hindley U.D.C (Hindley Green) -	0·59	0·050	0·17	0·42	4·8	0·80	6·5	—	5·5	1·0	Tanks and filters	Clear trace of sediment. No smell.
14	Chapel-en-la-Frith R.D.C.- -	0·70	0·074	0·18	0·42	2·7	0·05	6·3	6·0	5·9	0·4*	Tanks and land -	Clear, colourless. No smell.
15	Disley R.D.C. - - - - -	1·12	0·096	0·40	0·52	3·8	0·04	6·5	6·1	5·0	1·5***	Tanks and land -	Faintly turbid, no sediment. Soapy smell.
16	Abram U.D.C. - - - - -	0·63	0·049	0·31	0·52	—	0·60	6·5	6·1	5·9	0·6**	Bacteria beds -	Clear, colourless, traces of sediment. No smell.

NOTE. All the above samples were tested for the formation of nitrites during incubation after 24 hours and after 48 hours, but none were found except in those marked with asterisks, thus—
* Indicates formation of traces after 24 hours, but none after 48 hours. ** Indicate the formation of traces after 48 hours, but none after 24. *** Indicate the formation of traces after both periods.

TABLE 32.—Analyses of Sewage Effluents from Sanitary Authorities in the Mersey and Irwell Watershed, made during the months of August and September, 1900 (Scudder)—*continued.*

Chemical Results expressed in Grains per Gallon; Dissolved Oxygen in cc. per Litre—*continued.*

No.	Authority.	Ammonia.		Oxygen absorbed.		Chlorine.	Nitrates and Nitrites.	Dissolved Oxygen Test.				Method of Purification.	Remarks on Sample as received.
		Free.	Albuminoid.	3 mins.	4 hours.			At start.	After 24 hours.	After 48 hours.	Cc. consumed		
17	Lymm U.D.C.	0·65	0·050	0·11	0·54	5·7	0·02	5·6	5·4	4·7	0·9	Tank and willow beds.	Brown, with brown sediment. No smell.
18	Boldon U.D.C.	0·77	0·050	0·22	0·54	3·4	0·07	7·2	7·0	6·6	0·6	Tanks and land	Clear, colourless, traces of brown sediment. No smell.
19	Royton U.D.C.	1·82	0·095	0·23	0·55	4·3	0·03	6·8	5·4	4·4	2·4	Tanks and filters	Clear, little brown flocculent sediment. No smell.
20	Ashton-in-Makerfield U.D.C.	0·03	0·033	0·20	0·61	3·2	0·11	6·6	—	6·2	0·4	Tanks and land	Clear, trace of granular sediment. No smell.
21	Bucklow R.D.C. (Northenden)	0·74	0·077	0·27	0·69	3·8	0·14	6·4	5·8	5·6	0·8	Tanks and land	Brown colour, brown sediment, Very faint smell.
22	Bolton Corporation (Rhodes Farm)	0·63	0·047	0·38	0·69	6·5	0·23	6·5	6·3	5·9	0·6	Tanks and land	Clear, colourless, small amount of brown sediment. Very faint earthy smell.
23	Alderley U.D.C.	0·50	0·042	0·19	0·70	3·1	0·11	7·2	6·0	5·6	1·6	Tanks and land	Slightly turbid, traces of sediment. Faint soapy smell.
24	Wilmslow U.D.C. (S. Outfall)	0·03	0·028	0·24	0·71	2·5	0·14	7·3	7·1	7·0	0·3	Tanks and land	Clear, colourless. No smell.
25	Westhoughton U.D.C. (Rogers Farm).	0·56	0·087	0·26	0·74	5·9	0·28	7·7	7·0	7·0	0·7**	Tanks, filters, land.	Clear, brown sediment. No smell.
26	Worsley U.D.C. (Boothstown)	1·61	0·099	0·27	0·74	7·3	0·11	7·3	6·3	5·0	2·3	Tanks and land	Clear, trace of grey sediment. Faint earthy smell.
27	Macclesfield R.D.C. (Poynton)	0·56	0·067	0·20	0·74	3·5	0·03	6·5	6·1	5·9	0·6	Tanks and land	Clear, colourless, some grey sediment. Faint smell.
28	Oldham Corporation	0·98	0·151	0·43	0·80	6·0	0·05	6·8	5·7	4·7	2·1**	Tanks and filters	Faint turbidity, little grey sediment. Faint smell.
29	Mottram U.D.C.	0·42	0·095	0·25	0·82	2·5	0·22	6·5	5·6	5·5	1·0	Tanks	Liquid clear, trace of grey sediment. No smell.
30	Failsworth U.D.C.	0·79	0·12	0·36	0·84	5·9	1·82	6·5	5·6	4·7	1·8**	Tanks and filters	Faint turbidity, trace brown sediment. No smell.
31	Altrincham U.D.C.	0·77	0·088	0·34	0·84	—	0·13	6·7	6·2	5·5	1·2	Tanks and land	Brown, with brown sediment. Slight earthy smell.
32	Hale No. 2 Outlet	1·08	0·12	0·37	0·92	3·9	0·41	7·7	7·0	5·9	1·8*	Tanks and land	Almost clear, little brown sediment. No smell.

33	Stockport R.D.C. (Offerton) -	1·15	0·157	0·46	0·93	5·6	0·18	5·8	5·1	4·6	1·2	Tanks and filters	Pink colour, trace of sediment. Faint smell.
34	Denton U.D.C. - - - -	0·66	0·095	0·39	0·94	5·7	0·25	7·4	7·2	—	—	Tanks and filters	Almost clear, no sediment. Very faint smell.
35	Kearsley U.D.C. - - -	1·40	0·103	0·39	0·95	8·8	0·18	6·4	5·4	4·5	1·9*	Tanks and filters	Fairly clear, traces of grey sediment. No smell.
36	Swinton and Pendlebury U.D.C. (Pendlebury).	1·89	0·196	0·50	1·01	8·6	0·06	6·1	3·5	2·0	4·1	Tanks and filters	Liquid clear, little grey sediment. Slight earthy smell.
37	Urmston and Flixton J.S.B. -	0·77	0·141	0·47	1·09	5·2	0·10	6·3	5·1	3·8	2·5	Tank effluent -	Liquid faintly turbid. Trace of dirty sediment. Very faint smell.
38	Stockport Corporation - -	1·01	0·168	0·42	1·10	7·1	0·14	6·4	4·9	4·1	2·3	Tanks and land -	Faintly turbid, brown sediment. Faint smell.
39	Droylsden U.D.C. - - -	1·40	0·159	0·71	1·33	11·2	0·03	8·1	6·5	4·8	3·3	Tanks and filters	Faintly turbid, quantity of brown sediment. Faint smell.
40	Marple U.D.C. - - - -	3·15	0·227	0·55	1·34	7·5	0·04	6·0	3·0	0·9	5·1	Tanks and filters	Faintly turbid, trace of sediment. Faint smell.
41	Haslingden, Rawtenstall and Bacup S.O.B.	1·68	0·238	0·83	1·37	3·4	0·11	6·3	4·3	2·2	4·1	Tanks and land -	Faintly turbid, little fungus sediment. Slight smell developed.
42	Whitefield U.D.C. - - -	0·77	0·120	0·57	1·53	4·3	0·64	6·8	4·6	3·4	3·4***	Tanks and land -	Faintly turbid, trace of dark sediment. No smell.
43	Prestwich U.D.C. - - -	1·62	0·182	0·79	1·78	4·6	0·05	6·1	1·4	0·0	6·1+	Tanks and filters	Turbid, little grey sediment. Slight sour smell.
44	Tyldesley U.D.C. - - -	3·01	0·197	0·84	2·40	10·2	0·08	7·6	1·5	0·0	7·6+	Tanks and filters	Slightly turbid, trace of sediment. Slight sour smell.
45	Oldham Corporation - - -	2·38	0·291	1·23	2·82	5·0	0·02	6·5	1·8	0·0	6·5+	Tank effluent -	Turbid, black sediment. Putrescent smell.
46	Salford Corporation - - -	1·82	0·322	1·30	3·52	8·1	0·02	7·1	0·0	0·0	7·1+*	Tank effluent -	Grey, turbid, traces of grey sediment. Alkaline. Lime effluent smell.
47	Salford Corporation - - -	0·91	0·238	1·81	4·12	4·9	0·25	7·3	2·9	0·0	7·3+***	Tank effluent -	Grey, turbid, dark sediment. Alkaline. Nitrites present. Tarry smell.
48	Hyde Corporation - - -	4·06	0·655	1·48	4·74	27·2	0·00	7·4	0·0	0·0	7·4+	Tank effluent -	Grey, turbid. Putrescent smell.
49	Farnworth U.D.C. - - -	1·17	0·274	1·02	4·83	9·2	0·08	7·4	0·1	0·0	7·4+	Tank effluent -	Slightly turbid, finely divided sediment. Strongly alkaline. Lime effluent smell.
50	Manchester Corporation - -	2·45	0·456	3·97	7·24	12·1	0·00	7·1	0·0	0·0	7·1+	Tank effluent -	Brown, turbid, with dark sediment. Strong tarry smell.
51	Manchester Corporation - -	2·10	0·285	4·6	9·19	13·6	0·04	7·7	5·3	2·4	5·3	Tank effluent -	Brown, turbid, brown sediment. Very strong tarry smell.

NOTE.—All the above samples were tested for the formation of nitrites during incubation after 24 hours and after 48 hours but none were found except in those marked with asterisks thus—
* Indicates formation of traces after 24 hours, but none after 48 hours. ** Indicates the formation of traces after 48 hours, but none after 24. *** Indicate the formation of traces after both periods.

TABLE 33.—Analyses of Sewage Effluents from Sanitary Authorities in the Mersey and Irwell Watershed, made during the month of July, 1900 (Scudder).

Chemical Results expressed in Grains per Gallon: Dissolved Oxygen in cc. per Litre.

	Ammonia.		Oxygen absorbed.		Chlorine.	Nitrites and Nitrates.	Dissolved Oxygen Test.				Mode of purification.	Remarks on Samples as received.	About five days in the Incubator.		
													Oxygen absorbed.		Remarks.
	Free.	Albuminoid.	3 mins.	4 hours.			At start.	After 24 hours	After 48 hours	Cc. consumed.			Three minutes.	Four hours.	
1 Whitworth U.D.C.	0·43	0·056	0·076	0·34	4·0	7·58	6·7	5·9	5·2	1·5	Tanks and filters -	Clear, colourless. No sediment. No smell.	0·07	0·32	Clear, colourless, trace of sediment. No smell.
2 Barton R.D.C., Clifton	0·31	0·067	0·36	0·43	6·2	0·70	6·6	5·8	5·2	1·4	Tanks and filters -	Brown, brown sediment. No smell.	0·28	0 48	Clear, colourless, trace of brown sediment. No smell.
3 Little Lever U.D.C.	1·07	0·095	0·277	0·45	7·6	0·05	6·9	6·8	5·3	1·6	Filtered - - -	Almost colourless, light brown and dark sediment. No smell.	0·07	0·33	Clear, colourless, traces of sediment. No smell.
4 Littleborough U.D.C.	0·70	0·112	0·26	0·57	3·5	0·16	6·5	5·4	5·0	1·5	Precipitation and filtration.	Almost colourless, traces of brown sediment. No smell.	0·16	0·43	Colourless, traces of sediment. Slight smell.
5 Crompton U.D.C., Newhey	1·05	0·119	0·27	0·60	4·6	0·06	6·3	5·8	5·0	1·3	Precipitation and filtration.	Almost colourless, traces of brown sediment. No smell.	0·11	0·28	Colourless, light brown sediment. Slight smell.
6 Tottington U.D.C.	1·89	0·075	0·43	0·66	4·4	0·65	6·6	5·2	4·4	2·2	Tanks and land -	Turbid, brown sediment. No smell.	0·26	0·35	Clear, little sediment. Faint musty smell.
7 Westhoughton U.D.C., Rogers' Farm.	0·54	0·061	0·33	0·71	6·4	0·04	7·0	6·0	5·5	1·5*	Tanks, filters and land.	Liquid faintly brown, some dark brown flocculent sediment. No smell.	0·19	0·65	Light brown, brown flocculent sediment. No smell.
8 Radcliffe U.D.C.	0·378	0·077	0·24	0·72	5·6	–	6·5	6·4	5·0	1·5	Tanks and filters -	Almost colourless, small amount of sediment. No smell.	0·12	0·50	Almost colourless, trace of sediment. No smell.
9 Swinton & Pendlebury U.D.C., Pendlebury.	1·82	0·154	0·33	0·79	6·9	–	6·6	6·5	5·8	0·8*	Tanks and filters -	Light brown, brown sediment. Faint smell.	0·27	0·57	Clear, colourless, brown sediment. No smell.
10 Macclesfield Corporation.	0·41	0·095	0·34	0·85	3·7	0·02	6·5	4·9	4·2	2·3	—	Slightly turbid, trace of sediment. Slight smell.	0·61	1·16	Dark, with black sediment. Putrescent and sulphuretted hydrogen smell.
11 Turton U.D.C., Eagley.	1·61	0·21	0·43	0·86	3·6	0·01	7·2	4·6	2·7	4·5	Filtered - - -	Slightly turbid, brown sediment Faint smell.	0·72	1·12	Slightly dark, dark brown sediment. Faint smell of sulphuretted hydrogen gas.

12 Swinton & Pendlebury U.D.C., Pendlebury.	1·54	0·12	0·53	1·02	8·7	0·03	6·8	3·8	2·8	4·0†	Tanks and filters -	Slightly turbid, light brown sediment. Faint smell.	0·67	1·31	Dark colour, little dark sediment. Trace of sulphuretted hydrogen gas.
13 Turton U.D.C.	2·80	0·24	0·41	1·05	6·4	–	6·5	2·6	0·4	6·1	Tanks and filters -	Turbid, light brown sediment. Sewage smell.	1·3	1·55	Black, black sediment. Putrescent. Sulphuretted hydrogen gas.
14 Stockport R.D.C., Offerton.	1·19	0·114	0·41	1·12	2·0	0·02	6·4	4·8	3·0	3·4	—	Clear, coloured with eosine, trace grey sediment. Slight sewage smell.	0·87	1·41	Fluorescent, brown sediment. Earthy smell.
15 Hale U.D.C. -	1·54	0·185	0·40	1·14	3·8	0·02	7·0	2·8	1·4	5·6	—	Slightly turbid, no sediment. Sewage smell.	1·02	1·60	Black, with black sediment. Slight putrescent and sulphuretted hydrogen gas smell.
16 Gorton U.D.C. -	1·96	0·145	0·52	1·19	6·4	0·02	6·6	3·0	1·1	5·5	Tank effluent - -	Liquid turbid, faint grey sediment. Faint smell.	1·50	2·07	Slightly turbid, grey sediment. Slight putrescent and sulphuretted hydrogen gas smell.
17 Hindley U.D.C., Platt Bridge.	1·69	0·119	0·50	1·20	9·9	0·03	7·2	5·0	4·4	2·8	Tanks and land -	Slightly turbid, no sediment. Slight putrescent smell.	0·76	1·51	Dark, black sediment. Putrescent smell. Faint sulphuretted hydrogen gas.
18 Withington U.D.C.	1·75	0·154	0·74	1·35	4·3	0·02	7·6	6·7	5·5	2·1	Land - - -	Turbid, dark sediment. Strong earthy smell.	0·97	1·58	Dark, dark sediment. Earthy smell.
19 Haslingden, Rawtenstall, and Bacup, J.O.B.	0·42	0·201	0·60	1·38	4·3	0·03	6·6	3·7	1·5	5·1*	Tanks and land, no precipitation.	Light brown, turbid, finely divided grey sediment. No smell.	0·72	1·85	Dark, containing black sediment. Putrescent and sulphuretted hydrogen gas.
20 Knutsford U.D.C.	4·20	0·249	0·58	1·48	7·1	0·13	6·6	2·9	0·3	6·3	—	Slightly turbid, small quantity grey sediment. Slight smell.	0·78	2·01	Dark, with black sediment. Trace of sulphuretted hydrogen gas.
21 Tyldesley U.D.C.	3·44	0·154	0·79	1·50	9·0	0·03	6·9	3·7	1·1	5·8	Tanks and filters -	Slightly turbid, no sediment. Faint sour smell.	1·12	1·85	Dark, dark sediment. Putrescent smell. Sulphuretted hydrogen gas.
22 Rochdale Corporation, Sudden Valley Outlet.	1·71	0·259	0·62	1·68	4·2	0·07	7·2	4·6	3·3	3·9	Tank effluent - -	Fairly clear, little grey sediment. Faint sour smell.	0·55	1·80	Almost colourless, greyish brown sediment. Slight earthy smell.
23 Failsworth U.D.C.	3·01	0·154	0·72	1·71	5·8	0·00	6·7	2·0	0·0	6·7	Treated effluent -	Turbid, light brown sediment. Slight smell.	1·64	3·12	Dark, with little dark sediment. Little sulphuretted hydrogen gas.
24 Tottington U.D.C.	0·91	0·095	0·76	1·80	5·0	0·14	7·0	4·0	1·7	5·3*	Tanks and land -	Turbid, with dark brown sediment. Slight putrescent smell.	1·04	2·03	Black, black sediment. Putrescent smell. Sulphuretted hydrogen gas.
25 Withington U.D.C.	2·45	0·294	1·02	1·85	4·7	0·00	7·1	2·7	0·0	7·1	Land - - -	Dark, turbid, dark sediment. Putrescent smell.	1·83	2·6	Black, black sediment. Putrescent. Sulphuretted hydrogen gas.

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* Formation of nitrites indicated after 24 hours and after 48 hours.

† Formation of nitrites indicated after 24 hours.

TABLE 33.—Analyses of Sewage Effluents from Sanitary Authorities in the Mersey and Irwell Watershed, made during the month of July, 1900 (Scudder)—*continued.*

Chemical Results expressed in Grains per Gallon ; Dissolved Oxygen in cc. per Litre—*continued.*

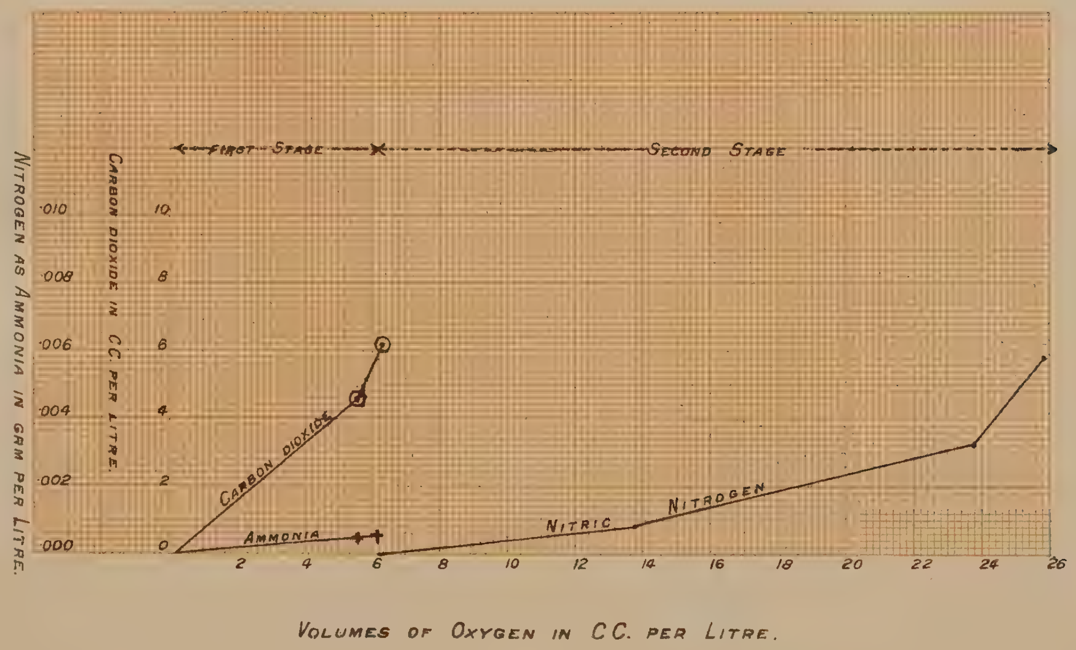
	Ammonia.		Oxygen absorbed.		Chlorine.	Nitrites and Nitrates.	Dissolved Oxygen Test.				Mode of purification.	Remarks on Samples as received.	About five days in the Incubator.		
													Oxygen absorbed.		Remarks.
	Free.	Album inoid.	3 mins.	4 hours.			At start.	After 24 hours.	After 48 hours.	CC. consumed.			Three minutes.	Four hours.	
26 Marple U.D.C. -	2·52	0·316	0·73	1·94	6·5	0·03	6·3	1·3	0·2	6·1	—	Slightly turbid, trace grey sediment. Faint earthy smell.	2·25	3·08	Black, black sediment. Putrescent. Sulphuretted hydrogen gas smell.
27 Prestwich U.D.C.	2·03	0·28	1·00	2·06	4·6	0·00	6·0	0·1	0·0	6·0	Part filtered - -	Turbid, dark sediment. Sewage smell.	3·08	12·75	Black, black sediment. Putrescent. Sulphuretted hydrogen gas.
28 Prestwich U.D.C.	1·84	0·476	0·87	2·23	3·9	–	6·1	2·7	0·0	6·1	Part filtered - -	Turbid, black sediment. Putrescent smell.	2·29	4·1	Black, black sediment. Putrescent. Little sulphuretted hydrogen gas.
29 Swinton & Pendlebury, U.D.C., Swinton.	1·47	0·201	1·04	2·71	10·7	0·00	6·8	1·3	0·0	6·8	Tanks, land and cinder	Light brown, dark brown sediment. Faint putrescent smell.	1·60	3·61	Dark liquid, black sediment. Sulphuretted hydrogen gas.
30 Norden U.D.C.	6·58	0·442	1·34	2·91	8·7	0·00	7·0	0·0	0·0	7·0	Tanks and filters -	Slightly turbid, trace sediment. Sewage smell.	3·77	5·0	Black, with black sediment. Putrescent smell. Sulphuretted hydrogen gas.
31 Oldham Corporation.	3·29	0·378	1·24	3·22	6·6	0·00	6·7	0·0	0·0	6·7	Tank effluent - -	Dirty brown, black sediment. Sewage smell.	4·65	6·52	Black, with black sediment. Putrescent. Sulphuretted hydrogen gas.
32 Rochdale Corporation, Roach Mills Outlet.	3·32	0·324	1·69	3·43	7.6	0·05	7·2	3·4	0·0	7·2†	Tank effluent - -	Liquid clear, little grey flocculent matter. Sour smell.	1·43	2·89	Almost colourless, greyish brown sediment. Trace of sulphuretted hydrogen gas.
33 Droylesden U.D.C.	1·61	0·198	1·16	4·40	9·3	0·00	6·7	2·1	0·0	6·7	Tank effluent - -	Brown, quantity brown sediment. Faint smell.	2·67	14·0	Black, black sediment. Putrescent smell. Sulphuretted hydrogen gas.
34 Bolton Corporation, Hacken.	3·29	0·523	3·03	6·92	11·2	0·00	7·3	0·0	0·0	7·3	Tank effluent - -	Dark brown, very turbid, dark sediment. Tarry smell.	3·67	6·5	Very dark brown, black sediment. Putrescent lime effluent smell.
35 Whitefield U.D.C.	1·75	0·168	0·56	1·72	5·3	0·68	6·6	4·2	3·0	3·6*	Tanks and land -	Turbid, brown sediment. No smell.	0·36	1·12	Slightly turbid, brown sediment. Slight smell.
36 Altrincham U.D.C.	1·12	0·148	0·60	1·58	7·8	0·56	7·0	6·5	5·1	1·9	—	Clear brown colour, trace of sediment.	0·41	1·13	Brown, with brown sediment. Faint musty smell.

* Formation of nitrites indicated after 24 hours and after 48 hours.

† Formation of nitrites indicated after 24 hours.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Diagram VIII. Curves showing the quantities of Oxygen absorbed, and of Carbon dioxide, formed during the First Stage, and of Oxygen absorbed, and of Nitrous and Nitric Nitrogen, formed, during the Second Stage, of Aërobic Fermentation, in a Sample of Polluted Water, collected from the River Mersey, just above its Junction with the Manchester Ship Canal, at Irlam Bridge.



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3. *Rate of Absorption of Dissolved Oxygen caused by De-aerated Water containing both directly and indirectly Oxidizable Substances, when mixed with Unpolluted Water.*

We give in the next two tables the results of some experiments with two samples of heavily polluted river waters, for which we are indebted to the kindness of Dr. Gilbert J. Fowler. They were collected under his supervision from the River Mersey, and from the Manchester Ship Canal, before their junction just below Irlam Bridge, about thirty yards above Mersey Weir.

Portions of each of these samples were enclosed, each with an excess of air, in well-stoppered bottles. The results of the experiments with them are given in the tables.

RIVER MERSEY.

TABLE 34.—Analyses showing the Rate of, and Total, Absorption of Oxygen in a Sample of Water collected from the River Mersey, just below Irlam Bridge, about 30 yards above Mersey Weir, at 9.30 a.m., October 3rd, 1905. Weather dry for some days previously. (Adeney.)

The following experiments were made with this sample:—

(1). The sample was first examined after it had been kept out of contact with air for 2 days after collection.
(2). A portion of it of known volume was then enclosed in a well-stoppered bottle together with a known volume of air, and was kept for 7 days, when both the air and the sample in the bottle were analysed.
(3). Another portion of the sample was similarly enclosed and kept for 14 days and analysed.
(4). Another portion was similarly enclosed and kept for 28 days.
(5). Another portion was similarly enclosed and kept for 34 days.
(6). Another portion was similarly enclosed and kept for 60 days.

The bottles were immersed during the time of keeping neck downwards in distilled water at the temperature of the laboratory.

Exp.	Gaseous constituents expressed as volumes at 0°C., and 760 mm. Bar., per 1,000 volumes of water.								Other constituents as parts by weight per 100,000 volumes of water.					
	Dissolved Gases.			Atmosphere in bottles.					Nitrogen as				Chlorine.	Solids in suspension.
				After fermentation.			Before fermentation.							
	Carbon dioxide.	Oxygen.	Nitrogen.	Carbon dioxide.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.	Organic.	Ammonia.	Nitrites.	Nitrates.		
1	45·81	0·0	15·29	–	–	–	–	–	0·19	0·4	0·0	0·0	8·12	43·5
2	46·74	5·68	14·40	3·63	48·15	235·1	62·05	233·43	0·18	0·15	0·0	0·0	–	–
3	47·94	5·52	14·41	4·0	52·75	257·36	67·50	253·92	0·17	0·45	0·0	0·0	–	–
4	49·64	4·28	14·80	4·4	39·[illegible]7	224·08	59·67	224·45	0·12	0·34	0·04	0·05	–	–
5	49·48	3·8	14·93	6·76	49·48	306·72	80·67	303·48	0·10	0·04	0·04	0·30	–	–
6	40·91	6·28	15·17	16·4	205·24	945·40	249·01	936·75	0·15	0·0	0·0	0·58	–	–

Total quantities of oxygen absorbed and of products formed by fermentation during each experiment:—

Exp.	Oxygen absorbed.	Products—			
		Carbon Dioxide.	Ammonia.	Nitrites.	Nitrates.
2	8·22	4·56	0·05	0·0	0·0
3	9·23	6·13	0·05	0·0	0·0
4	16·12	8·23	–	0·04	0·05
5	27·39	10·43	–	0·04	0·30
6	37·49	11·5	–	–	0·58

The sample when fresh was of a yellowish brown colour, and decidedly turbid. It contained small quantities of flocculent matters in suspension. Odour slightly offensive.

TABLE 35.—Analyses showing the Rate of, and Total, Absorption of Oxygen in a Sample of Water collected from the Manchester Ship Canal, just below Irlam Bridge, about 30 yards above Mersey Weir, at 9.30 a.m., October 3rd, 1905. Weather dry for some days previously. (Adeney)

The following experiments were made with this sample:—

(1). The sample was first examined after it had been kept out of contact with air for 2 days after collection.

(2). A portion of it of known volume was then enclosed in a well stoppered bottle together with a known volume of air, and was kept for 7 days, when both the air and sample in the bottle were analysed.

(3). Another portion of the sample was similarly enclosed and kept for 14 days, and analysed.

(4). Another portion was similarly enclosed and kept for 35 days.

(5). Another portion was similarly enclosed and kept for 45 days.

(6). Another portion was similarly enclosed and kept for 60 days.

The bottles were immersed during the time of keeping neck downwards in distilled water at the temperature of the laboratory, which varied between 12° and 16° C.

Experiment	Gaseous constituents expressed as volumes at 0°C., and 760 mm. Bar., per 1,000 volumes of water.									Other constituents as parts by weight per 100,000 volumes of water.			
	Dissolved Gases.				Atmosphere in Bottles.					Nitrogen as			
					After Fermentation.			Before Fermentation.					
	Sulphuretted Hydrogen.	Carbon Dioxide.	Oxygen.	Nitrogen.	Carbon Dioxide.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.	Organic.	Ammonia.	Nitrites.	Nitrates
1	4·16	82·63	0·0	15·33	—	—	—	—	—	0·18	0·8	0·0	0·0
2	0·0	88·46	5·45	14·70	11·55	99·00	506·5	133·86	503 59	0·15	0·88	0·0	0·0
3	0·0	89·77	5·4	14·71	12·2	100·25	535·15	140·86	529·89	0·12	0·9	0·0	0·0
4	0·0	80·25	2·42	14·75	23·20	73·9	544·65	143·28	539·02	0·12	0·0	0·16	0·64
5	0·0	81·39	3·30	14·68	23 7	59·45	491·25	129·34	486·56	0·13	0·0	0·0	0·75
6	0·0	80·45	3·55	15·42	23·85	65·00	513·9	134·91	507·53	0·12	0·0	0·0	0·93

Total quantities of oxygen absorbed in oxidation of sulphides, and by fermentation, and of the products of the latter formed, during each experiment. It should be noted that 7·28 c.c. oxygen per litre were absorbed in the oxidation of the sulphides.

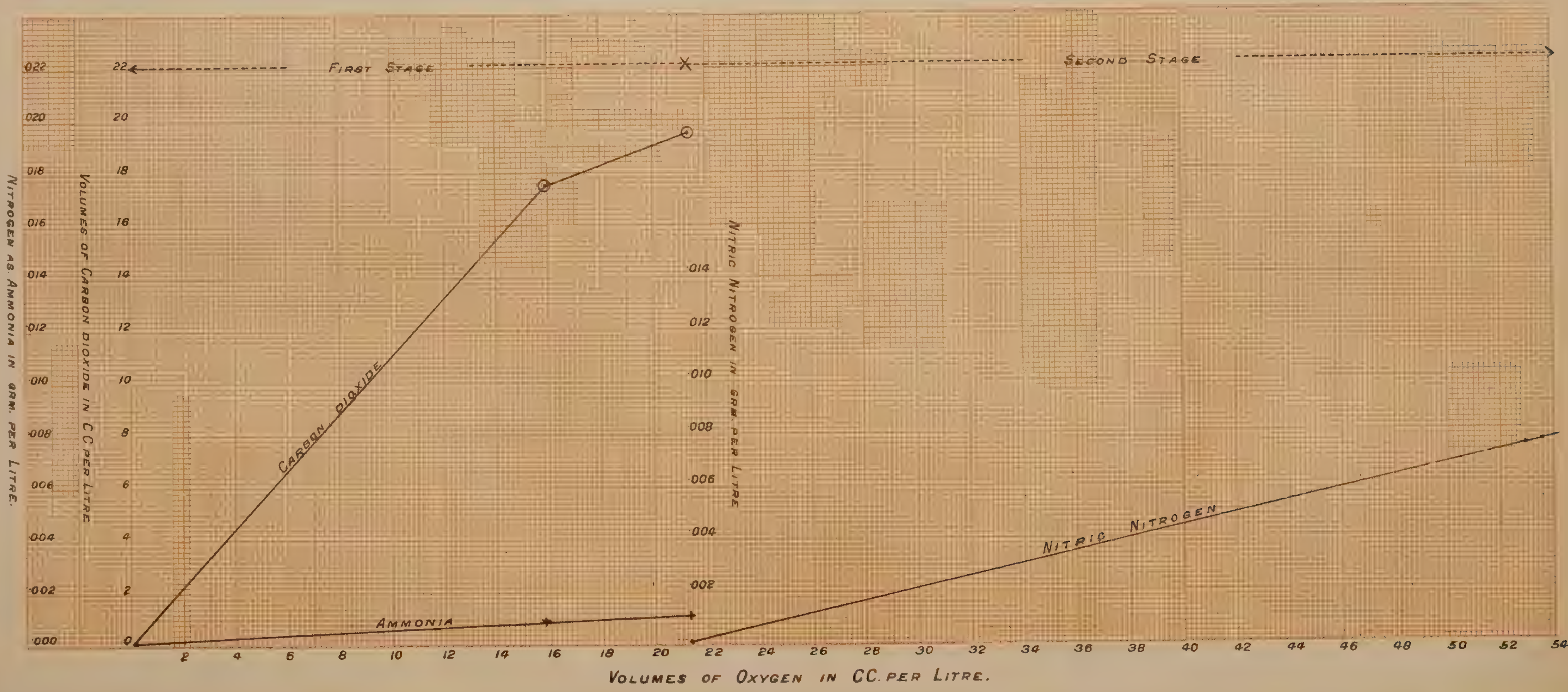
Experiment.	Oxygen absorbed.	Products.			
		Carbon Dioxide.	Ammonia.	Nitrites.	Nitrates.
2	29·41	17·38	0·08	0·0	0·0
3	35·21	19·34	0·1	0·0	0·0
4	66·96	20·82	—	0·16	0·64
5	66·60	22·46	—	—	0·75
6	66·36	21·67	—	—	0·93

The sample when fresh was a brownish black, turbid liquid, with small quantities of finely divided matters in suspension, and of an offensive putrefactive odour. It contained 72·5 parts of solid matter in solution, and 13·77 parts of chlorine per 100,000.

In all the experiments, the black ferrous sulphide was converted into red oxide in the course of two or three days from their commencement.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

DIAGRAM IX. CURVES SHOWING THE QUANTITIES OF OXYGEN ABSORBED AND OF CARBON DIOXIDE AND AMMONIA FORMED, DURING THE FIRST STAGE, AND OF OXYGEN ABSORBED, AND OF NITROUS AND NITRIC NITROGEN, FORMED DURING THE SECOND STAGE, OF AËROBIC FERMENTATION IN A SAMPLE OF POLLUTED WATER COLLECTED FROM THE MANCHESTER SHIP CANAL JUST ABOVE ITS JUNCTION WITH THE R. MERSEY AT IRLAM BRIDGE.



NOTE:- THE NITROUS NITROGEN HAS BEEN TAKEN AS EQUIVALENT TO 3/5THS NITRIC NITROGEN.

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On reference to the first four experiments with the Mersey sample, it will be found that the first stage of fermentation must have been nearly completed at the time it was collected, since they show that this stage only accounts for an absorption of 9·23 c.c. oxygen, and for the formation of 6·13 c.c. carbon dioxide, per litre.

When the results for the Experiments 3, 4 and 5 are compared together, we find that a period of rest, lasting several days, must have followed the first stage, and before the second stage had proceeded sufficiently to afford appreciable results.

Experiment 6 may be regarded as indicating the completion of both stages of fermentation, and we find from it that 37·49 c.c. oxygen were absorbed, and 11·5 c.c. carbon dioxide and ·0058 grm. nitrogen as nitrates were formed, per litre.

On comparing these results with those obtained for the average sample of sewage, Table 10, p. 28, it is seen that the strength of the sample as regards first stage fermentative substances was a little more than 1/10 of that of the sewage, and as regards second stage fermentative substances, about 1/10 also.

So far for the fermentative changes, but the sample was also completely de-oxygenated at the start, and we find from Experiment 2 that 5·68 c.c. oxygen per litre was taken up from the atmosphere in the flasks for re-aeration, in addition to the 8·22 c.c. which were absorbed by the fermentation. Under natural conditions, and according to the approximate rate of re-aeration in calm fresh water which we have adopted, viz., 0·72 c.c. oxygen per litre, per twenty-four hours, Table 24, p. 65, the re-aeration of large volumes of this polluted water would in calm weather take about eight days. By dilution with twice its bulk of air-saturated fresh water at 18° C., its aeration would be raised to 4·52 c.c. oxygen per litre, which is well above the minimum limit, 4 c.c., which we have adopted for fresh water. The rate of absorption of oxygen by fermentation in the mixture would also be decidedly less than that of re-absorption from the air. The sample thus diluted would therefore be, so far as aeration would be concerned, in no way dangerous to fish. A reservation must, however, be made in connection with this point. Such a dilution as here indicated was actually made with a portion of the original sample, and it was very turbid and dirty looking. We shall deal with this point when discussing the question of standards.

We may again refer to Experiments 3, 4 and 5 in order to point out that *they give the means of calculating the rate of absorption of oxygen during the second stage of fermentation, it was equal to* 3·8 *c.c. per litre in forty-eight hours.*

The results of the experiments with the sample from the Manchester Ship Canal show that it was not only much more heavily polluted with fermentative organic matters than the Mersey sample, but also contained decided quantities of easily oxidisable sulphides; it was also completely de-aerated.

Experiment 3 indicates the complete oxidation of the sulphides and also the completion of the first stage of fermentation, and the results show that 35.21 c.c. per litre oxygen in all were absorbed, 7·28 c.c. for the oxidation of the sulphides according to the equation—

$$4\,FeS + 7\,O_2 + 2\,H_2O = 2\,SO_2 + 2\,Fe_2H_6O_6$$

and 27·93 c.c. for the true fermentative, and other possible oxidation, changes, while 19·34 c.c. carbon dioxide per litre were formed; 5·4 c.c. per litre were in addition taken up for re-aeration.

The oxidation of the sulphides may be taken as having been completed in forty-eight hours, since the conversion of the black ferrous sulphide in the sample to the red ferric hydrate was very nearly, if not entirely, complete in this time.

Experiment 2 shows that the oxygen absorbed by fermentative changes in seven days was 29·41 − 7·28 = 22·13 c.c. per litre, or 6·3 c.c. in forty-eight hours, assuming that the rate of absorption by fermentation changes was uniform during the seven days.

The total absorption by direct oxidation and fermentative changes therefore amounted to approximately 13·6 c.c. oxygen per litre in forty-eight hours.

The question arises, To what extent would such a sample have to be diluted to ensure that the rate of absorption of dissolved oxygen in the mixture should not exceed the maximum allowable limit?

Suppose the water were diluted with three times its volume of fully aerated sea water at 18° C., = 5·51 cc. oxygen per litre, the aeration of the mixture would be equal to 4·13 c.c. oxygen per litre, and the rate of absorption in it due to the direct oxidation of the sulphides, and to fermentative changes, would be approximately one-fourth the absorption above found for these two causes in the undiluted sample, viz., nearly 3·4 c.c. per litre. On keeping therefore the mixture for forty-eight hours out of contact with the air, its aeration would be reduced to 0·73 c.c. oxygen per litre. Hence dilution with three times its volume of sea water would produce a mixture in which the rate of absorption of dissolved oxygen from all causes would just exceed the maximum allowable limit which we have adopted; and it must be added that such a mixture on being made remained very turbid and discoloured for some time, and that it is doubtful to what extent the sulphides and other possible products of previous anaerobic fermentation which may have been present, would affect fish life.

Experiment 4 was continued for twenty-one days longer than Experiment 3, and during this extended period the whole of the ammonia was oxidised chiefly to nitric acid. If we allow seven days for the period of rest between the two stages of fermentation, we get fourteen days as the time in which the second stage was practically completed, and during it 31·75 c.c. oxygen per litre of the sample was absorbed, which is at the rate of 4·5 c.c. for forty-eight hours, which would be much too rapid to allow in a tidal water for a period extending over forty-eight hours.

On comparing the results of complete fermentation of this sample with those for the average sample of sewage already referred to, we find that it was a little less than one-fourth the strength in carbon oxidisable substances, and about one-sixth its strength in nitrifiable substances.

SAMPLE OF POLLUTED TIDAL WATER CONTAINING SULPHIDES IN SUSPENSION.

The experiment, which is recorded in Table 35A, which follows, was made by the same author with a sample of polluted tidal water after it had been kept for a week out of contact with air, when it had become completely de-aerated and very offensive from products, more particularly sulphides, of anaerobic fermentation. The rate of absorption of oxygen caused by the sample in this condition when gently shaken in a closed vessel with an excess of air was determined by a method which will be subsequently described (pp. 101–105).

TABLE 35A.—Determinations of the Rates of Absorption of Oxygen by a Sample of Polluted Tidal Water showing that Directly Oxidisable Products of Anaerobic Fermentation may absorb Oxygen much more quickly than Indirectly Oxidisable Substances.

Time.	Oxygen absorbed expressed in c.c. per litre, at N.T.P.	Time.	Oxygen absorbed expressed in c.c. per litre, at N.T.P.
First day (24 hours) after commencement.	57·5	Sixth day - - - - -	6·0
		Seventh day - - - -	6·2
Second day - - - - -	8·5	Eighth day - - - -	6·2
Third day - - - - -	4·8	Ninth day - - - -	3·7
Fourth day - - - - -	5·8	Tenth day - - - -	0·0
Fifth day - - - - -	5·0		

The sample at the commencement of the experiment contained black ferrous sulphide in suspension. At the end of 24 hours the black colour had entirely disappeared, so that it may be taken that most, if not all, of the sulphides present had been oxidised by this time, when 57·5 c.c. oxygen per litre had been absorbed. During the next 8 days the indirectly oxidisable substances suffered fermentation, as shown in the above table. The total volume of oxygen which they absorbed in that time was 46·2 c.c. per litre. Thus the easily oxidisable substances absorbed more oxygen in one day than did the indirectly oxidisable substances in the same polluted water in 8 days.

RIVER LIFFEY.

We have already summarised some experiments with samples of the Estuary waters of the Liffey, Table 30, p. 77. The samples were collected at points where they were polluted by the sewage discharged from the Rathmines and Pembroke Main Drainage Outfall, a sewage which, as already explained, contains practically no products of putrefaction, owing to the large quantities of nitrates and nitrites which it contains. It consequently only affects the aeration of the tidal waters through the fermentative substances it contains, and through its own state of more or less complete de-aeration.

We now have to consider some investigations which have been made of the waters of the tidal portion of the River Liffey. This portion of the river is only about 2½ miles long and less than 200 yards wide. The greater portion of the Dublin sewage is discharged in a crude state along the upper reach of this part of the river. The solid matters of the sewage are deposited along its bed, which is in consequence in an exceedingly foul condition, masses of black mud frequently rising from it to the surface of the water. Ferrous sulphide and other products of putrefaction are in this way disseminated through the water in a finely divided state. The dissolved oxygen of the clean tidal water is thus liable to be taken up in all three different ways already enumerated.

The influence of the foul condition of the river bed on the aeration of the tidal waters is at once seen on comparing the results in the succeeding table with those from the Estuary samples just referred to.

It is evident from the quantities of free ammonia recorded in the table that the proportion of liquid sewage matters in the tidal portions of the river can seldom exceed 5 per cent., and must be frequently less. The percentage is less, in fact, than in some of the samples collected from the Estuary, *see* Table 30, and yet the aeration is also very distinctly less. It is therefore reasonable to assume that the greater consumption of dissolved oxygen in the river samples must have been caused by the presence in them of the easily oxidisable products of putrefaction already referred to.

TABLE 36.—Analyses showing the state of Aeration of the Waters of the Tidal Portion of the River Liffey, which receives the whole of the Dublin Sewage in the crude condition. The solid matters of the Sewage are deposited along the bed of this portion of the River, and it is consequently always in a very foul state. The Oxygen absorbed from its tidal waters is therefore taken up not only by Aerobic Fermentative Changes, but also by the de-aerated River water, and by de-oxygenated products of anaerobic fermentation, *e.g.*, sulphides and reduced organic substances. Gaseous constituents expressed in c.c. at 0°C., and 760 mm. bar., per 1,000 volumes, and other constituents in parts by weight per 100,000 volumes of water (*Adeney*).

	1904.	Samples.	Temp °C.	When collected.	State of tide.	Wind.	Time kept.*	Carbon dioxide	Oxygen.	Nitrogen.	Nitrogen as Ammonia.	Chlorine.
1	July 12	Surface sample†	17·5	10.7 a.m.	¼hr. ebb.	E.S.E.	5 hrs.	53·75	3·04	11·50	0·063	1593
2	,, ,,	30ft. below surface	17·9	,, ,,	,,	,,	6 ,,	47·56	3·65	10·83	0·026	1902
3	,, 14	Surface sample†	16·4	1.25 p.m.	1¾hr. ebb	S.E.	20 ,,	47·72	3·02	11·78	0·018	1672
4	,, ,,	28ft. below surface	15 8	,, ,,	,,	,,	21 ,,	43·76	4·68	11·57	0·02	1866
5	,, ,,	Surface sample a little lower down river - - -	16·3	1.37 p.m.	2hrs. ebb	S.E.	22 ,,	51·64	3·16	11·58	0·028	1705
6	,, ,,	Surface, off mouth of River Dodder -	17·2	3.20 p.m.	3¾ ,, ,,	,,	24 ,,	66·67	0·26	12·77	0·172	1048
7	,, ,,	Do. bottom sample	16·0	,, ,,	,, ,, ,,	,,	25 ,,	51·15	1·65	11·94	0·025	1775
8	,, 20	Surface sample†	17·0	10.20 a.m	L. water	E.	5 ,,	48·29	0·12	12·35	0·095	1043
9	,, ,,	11½ ft. below surface - - -	16·0	,, ,,	,, ,,	,,	6 ,,	46·07	3·63	12·12	0·021	1792
10	,, 21	Abreast Ringsend‡ - -	17·9	11.30 ,,	L. water	S.	3 ,,	48·33	0·95	12·33	0·092	993
11	,, ,,	Ditto, 21½ ft. below surface - -	16·0	,, ,,	,, ,,	,,	4 ,,	40·22	4·05	11·48	0·015	1824
12	,, 26	Surface sample†	16·6	10.45 a.m	¼ hr. ebb	N.E.	3 ,,	60·53	2·36	12·46	0·06	1262
13	,, ,,	30ft. below surface	15·8	,, ,,	½ ,, ,,	,,	4 ,,	47·85	4·47	11·59	0·023	1813
14	Nov. 7	Non-tidal water, just above Weir at Island Bridge-	11·0	11.0 a.m	– –	—	2 ,,	79·77	6·73	15·36	0·01	1·4

NOTES.—July 12. The surface of the river water was much discoloured. The wind was fresh. All the samples collected contained small quantities of finely divided solid matters in suspension.
,, 14. River water much discoloured. Strong breeze. All the samples contained slight quantities of finely divided solids in suspension.
,, 20. Much rain previous day and night, river water much discoloured.
,, 21. River water less discoloured. Fairly strong wind.
,, 26. River water much discoloured. Wind strong, weather damp.

At the time the above samples were collected, the bed of this portion of the river was exceedingly foul, patches of black mud frequently rising from it to the surface of the water. The river water was not offensive, owing to its admixture with clean tidal water.

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* The bottles in which the samples were collected were completely filled, and carefully stoppered, so as to leave no air in them. The time each sample was kept is given in this column.

† These samples were collected at a point in the river abreast of Martin's Ferry Steps.

‡ These samples were collected in the higher reach of the Estuary of the river.

River Thames.

The results of analysis of a number of samples which were collected from the surface and bottom waters of the Thames during our inspection of that river in August 1904, are given in the succeeding table. We were indebted to the kindness of Dr. McGowan for allowing us the use of his laboratory for making some of the analytical determinations. Our acknowledgments are also due to Mr. R. B. Floris, F.I.C., for his kind assistance in making some of these determinations.

Table 37.—Analyses showing the State of Aeration of the Surface and Bottom Waters of the Tidal Portions of the River Thames, August 24th and 26th, 1904. Gaseous constituents expressed in c.c. at 0°C, and 760 mm. bar., per 1,000 volumes, and other constituents in parts by weight per 100,000 volumes of water.

No.	Date. 1904.	Particulars of Samples.	State of Tide.	At time of collection.			24 hours later, the samples having been kept out of contact with air.			
								Nitrogen as—		
				Temp.	Chlorine.	Dissolved Oxygen.	Dissolved Oxygen	Ammonia.	Nitrates.	Nitrites.
1	Aug. 24	Abreast of Becton Gas Works, surface sample	High water*	17·4	800	1·44	1·20	·23	—	—
2	”	Ditto, bottom sample -	” ”	16·6	830	—	1·00	·21	·085	·013
3	”	200 yards below Crossness, surface sample	” ”	17·4	984	1·4	1·06	·095	—	·008
4	”	Ditto, bottom sample -	” ”	16·6	1000	—	1·10	·08	—	trace
5	”	Abreast Purfleet, surface - - -	1½ hrs. ebb -	17·6	1100	1·55	1·29	·032	—	trace
6	”	Ditto, bottom - -	” ”	16·6	1116	—	1·1	·028	·19	0·2
7	”	At Grays, surface -	2 hrs. ebb -	17·4	1216	1·80	1·50	·014	—	0·0
8	”	Ditto, bottom - -	” ”	16·4	1210	—	2·65	·018	·23	·005
9	”	At Mucking, surface -	3½ hrs. ebb -	17·4	1486	3·5	3·4	·005	—	0·0
10	”	Ditto, bottom - -	” ”	16·2	1550	—	4·4	·002	—	0·0
11	”	Chapman, surface -	4½ hrs. ”	17·2	1638	4·4	4·5	·004	—	0·0
12	”	Ditto, bottom - -	” ”	16·3	1644	—	4·55	·006	·08	0·0
13	Aug. 26	Chapman, surface -	High Water†	17·2	1796	5·2	5·38‡	·013	·039	0·0
14	”	Ditto, bottom -	” ”	17·4	1940	—	5·04‡	·007	·003	0·0
15	”	Off Cliffe in the Lower Hope, surface -	2 hrs. ebb -	17·4	1600	4·15	4·06‡	·012	·092	0·0
16	”	Off Grays, surface -	3 hrs. ebb -	17·5	1210	2·07	1·60	·0114	·21	0·0
17	”	Above Purfleet, surface	4 hrs. ebb -	17·6	940	0·87	—	·12	·11	·014
18	”	Half-mile below Crossness, surface - -	4½ hrs. ebb -	17·5	700	0·65	0·1	·289	·038	trace
19	”	N. Woolwich, surface -	5 hrs. ebb -	17·2	430	0·40	0·04	·300	·114	·010

Portions of samples 18 and 19 were diluted each with 4 times its volume of distilled water, aerated and examined as follows:—

Sample.		Dissolved Gases.			Nitrogen as—		
		Carbon Dioxide.	Oxygen.	Nitrogen.	Ammonia.	Nitrates & Nitrites.	Organic.
18	When freshly prepared -	16·47	6·31	12·87	—	—	—
”	After keeping 12 days out of contact with the air - -	20·89	1·89	12·83	·085	·012	·040
19	When freshly prepared -	16·57	6·39	12·93	—	—	—
”	After keeping 12 days out of contact with the air - -	19·90	3·15	12·93	·065	·020	·048

Note.—All the samples contained more or less large quantities of suspended matters, and these contained traces of carbonates.

* High water at Crossness. † High water at Chapman. ‡ These determinations were made by the Eudiometric method, all the unmarked ones were kindly made for us by Mr. R. B. Floris, F.I.C., by Winkler's method as modified by Rideal and Stewart.

It appears from the ammonia determinations that the quantity of sewage in the most polluted samples did not exceed 10 per cent. The air saturation value of the tidal water at the temperatures recorded would be about 6·3 c.c. oxygen per litre, assuming the waters to be composed of equal proportions of fresh and salt waters. This value would be reduced to 5·1 c.c., if the tidal waters had been mixed with 10 per cent. of de-aerated sewage, on the assumption that the latter did not contain appreciable quantities of easily oxidisable substances.

On reference to the determinations of the dissolved oxygen given in the table, it will be found that they are much lower than this figure. It might be urged that the cause of this was the absorption of oxygen by the aerobic fermentation of the sewage matters. No doubt the reduction of the aeration is partly to be referred to this, but apparently not wholly, since the actual rate of absorption of oxygen from all causes at the time of collection is shown by the results to have been very slow, not more than 0·5 c.c. oxygen per litre, with one exception, when it was 0·8 c.c., per twenty-four hours.

Some other cause or causes must, therefore, have existed for the excessive absorption of oxygen, just as we have already pointed out was found to exist in the tidal portions of the River Liffey. It is difficult to see any other explanation for it than that already given, viz., the presence of easily oxidizable substances, possibly products of putrefaction among the suspended matters in the water, originating from sewage solids deposited from time to time along the bed of the river.*

PART XII.

STANDARDS FOR TIDAL WATERS BASED ON AERATION.

Since tidal waters cannot be used for potable purposes, it is only necessary to adjust standards of impurity for sewage matters, to be discharged into them, for the protection of fish life. If this be done the interest of public health will also be safeguarded. Tidal waters which do not present unhealthy conditions to fish would certainly not be a danger to public health, except perhaps in special cases, in which the sewage might be conveyed to bathing localities, or to shell fish layings. Such cases, however, involve bacteriological investigation as well as chemical, and are, therefore, beyond the scope of this Report. It is sufficient here to remark in reference to them, that it obviously is a matter of common prudence that bathing sites should not be chosen at any place likely to be affected by sewage discharged from an existing and adjacent outfall; and that outfall should not be permitted in dangerous proximity to an existing bathing locality or to a shell fish laying.

The investigations which have been made upon the effect of sewage matters on fish (*pisces*), have been summarised in another section of this Report.† From them it will be seen that the more important ways in which sewage may injure fish are as follows:—

(1) They may carry with them substances which are directly poisonous to fish.

(2) They may be the indirect cause of the death of fish, by de-aerating the water into which they are discharged, and causing asphyxia.

Solid matters may cause injury to fish by—

(*a*) Fouling the bed of the river or estuary, when they will render it unsuitable for spawning, and will also undergo fermentation and give rise to the formation of poisonous and of de-aerating products of putrefaction.

(*b*) Causing mechanical injuries to them, or by clogging their gills.

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* See also Section on the River Humber, p. 325.

† Pollution of Water in Relation to its Effects on Fish (*Pisces*), p. 201.

It does not appear that liquid sewage matters, when free from directly poisonous substances, exercise any injurious effect on fish, if present in comparatively small quantities only.

The effects of poisonous chemicals on fish, so far as they have been studied will be found tabulated in the section referred to, p. 217.

Obviously the reasonable precaution to be adopted by sanitary authorities against the danger of such substances is to prevent their admixture with sewage in quantities sufficient to cause injury to fish; or to require that the sewage shall be treated so as to prevent their discharge in a crude or dangerous condition into tidal water.

Sewage in a highly putrefactive condition should also, as far as possible not be allowed to be discharged into tidal waters.

The discussion of the question of standards which we now propose to take up, will be subject to the exclusion from sewage of directly poisonous matters of all kinds.

As regards the solid matters of sewage, we have been forced to the conclusion from the observations which we made during our inspection and investigation of the more important estuaries round the English coast in August, 1904, and from our general experience, that sewage solid matters should not be discharged into tidal waters except when strong tidal currents are available by which they may be mechanically broken up and carried away, and so widely distributed in open water that they cannot possibly form permanent accumulations anywhere.

As regards liquid sewage matters, there appears to be a practical unanimity of opinion amongst local authorities, that they do not, when free from poisonous chemicals and from the products of putrefaction, constitute a danger to fish, unless present in sufficiently large proportions seriously to reduce the aeration of the waters with which they become mixed.

All the evidence which we have been able to gather goes to show that the prevention of undue de-aeration in all cases of pollution of tidal waters by sewage matters, must form the primary object to be aimed at in the formulation of standards. If this be done, not only will fish life be safeguarded, but all possibility of fouling the waters or the foreshores and beds of tidal rivers or of sea borders will also be avoided.

It may be desirable and indeed necessary sometimes to secure other objects in formulating standards for certain special cases. For instance, the prevention of the growth of undesirable seaweeds, such as the *Ulva Latissima** in localities which present otherwise favourable topographical conditions for their establishment; or the prevention of discolouration of tidal waters by sewage matters in the neighbourhood of health resorts. These, however, must be regarded as special cases, and must be met by special local regulations; but even with these, the prevention of undue de-aeration must form the first consideration.

From our discussion of the question of the maximum rate of absorption of dissolved oxygen in tidal waters, we have ascertained as definitely as our present knowledge permits, the limits of de-aeration which can be allowed under calm weather conditions in each of the three great classes into which, as we have pointed out, tidal waters may be roughly divided for the purpose. The difficulty is so to base standards upon them, that the waters may be adequately protected from any form of over-pollution, and that at the same time the local authorities may avail themselves to the full extent of all the facilities which the tidal waters of their district offer for the disposal of sewage.

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* See Section of this Report on "Indirect Nuisances caused by Green Sea-weeds."

Before attempting the formulation of standards, it seems desirable to adopt some common understanding in reference to the position of outfall sewers. They should certainly be required to be fixed as far as practically possible in such positions that full advantage may be taken of any natural conditions favourable for the transport of sewage, arising from the strength and direction of tidal currents. No outfall sewer, for instance, should be allowed to discharge on the foreshore which is stripped at every tide, nor into slack water.

Some instances of the advantages which have followed correction as regards mistaken positions of outfall sewers will be found noted in the Appendix to this Report, in which are given the replies to a series of questions which were addressed to the Medical Officers of Health of certain towns situated upon tidal waters. For example, Plymouth, where a main intercepting sewer has been laid by which the sewage is discharged on the ebb tide in deep water, and where formerly it was discharged at different points inshore and a nuisance was created. At Newport (Mon.) a nuisance was caused from one of the outfalls discharging into slack water. The outfall has been taken out into the river where it delivers into the strong current there, and good results have followed.

Having given a suitable position for the outfall sewers, so far as practically obtainable, the question arises how best to state in the form of a standard the amount of pollution which the tidal water can bear.

We can of course only suggest in the broadest outline a standard for each of the three classes of tidal waters, referred to in Part XI, p. 67.

It appears to us on careful reflection that a good practical method for estimating the capacity of a given tidal water to deal with a given sewage would be to determine as nearly as possible the extent to which the water would dilute the sewage or sewage effluent discharged into it at a given distance from the outfall under calm weather conditions, and at a given state of the ebb or flood tide.

In the case of an existing outfall, this does not present any great difficulty. A practical example is afforded by the analyses by one of the authors (Adeney), which are given in the appended table 38. Samples of the surface and bottom waters were collected from the lower portion of the estuary of the Liffey, at points vertically over the Rathmines and Pembroke Townships Main Drainage Outfall, and along the path taken by the sewage, in calm weather, and during the fifth hour of an ebbing neap tide, when the strength of the tidal current is at about its minimum.

The analyses clearly show that the sewage after discharge in calm weather rises to the surface of the tidal waters flowing over the outfall, and in doing so becomes diluted with about an equal volume of tidal water, and that this mixture is borne away on the surface of the tidal waters, mixing with them very slowly, even in the vertical direction. Thus at a distance of 10 yards from the outfall the dilution is just four times greater than over the outfall, at 50 yards distance the dilution is practically identical, and at 100 yards distance, it is only very slightly greater, the original sewage matters having become mixed by the time they reached this point with just about nine times their volume of tidal water. At a distance of 800 yards from the outfall, they had become mixed with just nineteen times their volume of tidal water. Ample evidence will be found in our Section on the River Liffey to show that this state of things generally obtains in calm weather, and in the absence of strong eddy currents.

It is quite evident from the quantities given in the table for the dissolved oxygen found in the samples after keeping them out of contact with the air for several days, that the tidal waters could have disposed of much larger volumes of the sewage without danger to their aeration.

TABLE 38.—Analyses of Samples of Surface and Bottom Waters collected from the Estuary of the River Liffey, showing that Sewage after Discharge from a Submerged Outfall Sewer rises to the surface of the Tidal Waters and very slowly mixes with them in calm weather. (High-water at 4.55 a.m. Weather very dry and calm; no rain for the previous seven days, with light E. and N.E. winds. Temperature of water at surface, 8°C.) (*Adeney*).*

No.	Surface and Bottom Samples. Where collected ; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 vols. of water.				Other constituents as parts by weight per 100,000 parts of water.						
							Nitrogen as					Solids in suspension.	
			Carbon dioxide.	Oxygen.	Oxygen in per cent. of saturation†	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solids in solution.	Inorganic.	Organic.
	Sewage from Penstock -	3 hours	113·73	3·83	—	16·75	·300	·750	·130	191	446	1·135	3·365
1	Over Outfall‡ at 9.5 a.m. - - -	4	85·05	5·27	68·84	15·31	·160	·340	·060	837	1651	1·285	0·715
2	10yds. below Outfall in path of sewage, and 2 ft. below surface at 9.9 a.m. - - -	5 ,,	53·73	6·24	89·76	13·90	·004	·051	·086	1575	3057	Traces	
3	Ditto at surface, at 9.12 a.m. - - -	6 ,,	63·20	5·95	82·22	14·47	·042	·158	·088	1295	2527	Traces	
4	50yds. below Outfall and 2 ft. below surface at 9.14 a.m, in path of sewage -	30 ,,	54·27	6·15	86·74	14·17	·015	·013	·045	1554	3066	Traces	
5	Ditto at surface, at 9.17 a.m. - - -	31 ,,	60·96	5·77	79·72	14·48	·042	·083	·010	1313	2565	Traces	
6	100yds. below Outfall and 4 ft. below surface, in path of sewage, at 9.19 a.m.	7 days	52·97	5·35	76·32	14·02	·012	·028	·042	1617	3135	Traces	
7	Ditto at surface, at 9.22 a.m. - - -	7 ,,	61·27	4·80	67·32	14·26	·032	·086	·038	1348	2614	Traces	
8	800yds. below Outfall and 7 ft. below the surface, at 9.30 a.m.	10 ,,	50·47	6·11	87·54	13·96	·006	·016	·054	1663	3280	Traces	
9	Ditto at surface, at 9·32 a.m. - - -	10 ,,	59·27	4·37	61·29	14·26	·015	·035	0·64	1400	2711	Traces	

The capacity of tidal waters to dispose of the sewage matters discharged into them must obviously be defined for a given state of tide ; the distance from the outfall at which the test samples are to be collected must also be defined.

These two questions can only definitely be settled by careful investigation both in the laboratory and on the open water for typical localities. From our own experience we believe that the distance from the outfall might be fixed at about 200 yards ; and that the state of tide selected, should vary according to whether the sewage is, or is to be, discharged on the ebb tide only, or at all states of the tide or during any portion of the flood tide as well as the ebb. Under the former condition the selected state of the tide might be that occurring at the fourth hour of the ebb, but under the latter condition, it would be safer, we think, to take it at low water.

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* "Studies in Chemical Analysis of Fresh and Salt Waters," Scientific Proceedings of the Royal Dublin Society, 1900, p. 356.

† The figures in this column have been calculated on the basis that the volume of oxygen required for saturation was equal to half the volume of nitrogen in them.

‡ The Rathmines and Pembroke Outfall Works.—Sample 2 was collected perpendicularly over the Outfall when it was covered by about 2 feet of water.

In those cases in which an outfall does not exist, but a position for one has been selected, the diluting power of the tidal waters may be roughly gauged by discharging into them a strong solution of eosin or of other suitable colouring matter near the selected position, in calm weather, and collecting samples along the path taken by them. The degree of dilution of the colouring matters in these samples could be approximately estimated by comparing them with known dilutions of some of the solution originally employed.

Subject to the foregoing considerations, we may formulate standards for each of the three classes of tidal waters as follows :—

Standard for Class 1, which may include tidal waters the currents of which are strong enough to transport all sewage matters, including suspended solids, from the neighbourhood of the outfall, and so widely to distribute them through large volumes of sea water as to render them practically innocuous before change of tide.

Tidal currents which ebb with sufficient strength to carry all sewage matters discharged into them, both solid and liquid, and widely to distribute them in open water before change of tide, will also under most circumstances be in sufficient bulk to dilute them to such an extent as quickly to render them practically innocuous. We have an example of this in the successful disposal of the sewage matters of Portsmouth. These are stored in tanks of 4½ million gallons capacity, and are thence discharged into the Langstone Channel during the second hour of the ebb tide, and are carried away by the tidal currents into the English Channel.

It does not seem necessary to formulate a standard for such favourably situated tidal waters.

There are localities, however, *e.g.*, Newport (Mon.), where crude sewage is discharged into narrow tidal ways at all states of the tide, and are, moreover, satisfactorily disposed of by the tidal scour. But from our inspection of the River Usk at Newport in August, 1904, we formed the opinion that it would not be safe largely to increase the volumes of sewage then being discharged into the river in the crude state. It seems to us, therefore, that a limit should be placed upon the quantity of crude sewage which may be discharged into tidal ways more or less favourably situated for their adequate disposal.

The standard to meet these cases should be formulated in accordance with the above considerations thus :—

> The aeration of a sample of mixed sewage and tidal water collected at low water (average tide) in calm dry weather at any point 200 yards from the outfall, or of a sample of the sewage when mixed with tidal water in the proportion of the ascertained diluting power of the latter at the given distance when such mixture is kept out of contact with the air for 12½ hours at 18°C., shall not fall below 2·8 c.c. oxygen per litre.*

Standards for Class 2, which may include tidal waters, the ebb currents of which can transport liquid sewage matters, and widely distribute them in open water.*

Liquid sewage matters, when the solid matters have been previously separated from them, may be discharged into this class of tidal water either (*a*) on the ebb tide only, or (*b*) at all states of the tide or during some portion of the flood tide as well as of the ebb.

(*a*). *Discharge on the Ebb Tide only.*

The standard may be formulated thus—the aeration of a sample of mixed sewage and tidal water collected at the commencement of the fourth hour of the ebb of an average tide in calm dry weather at any point 200 yards from the outfall, or of a sample of the sewage when mixed with tidal water in proportion of the ascertained diluting power of the latter any point, at the given distance, when either is kept out of contact with the air for 6¼ hours at 18°C., shall not be less than 3·1 c.c. oxygen per litre.

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* See Appendix by Dr. Fowler, p. 555.

(*b*). *Discharge at all States of the Tide.*

The standard may be formulated similarly to the one above given for Class 1.

Standard for Class 3, which includes all other tidal waters not so favourably circumstanced.

Liquid sewage matters may also be discharged either (*a*) on the ebb tide only, or (*b*) at all states of the tide, or during some portion of the flood tide as well as of the ebb.

(*a*). *Discharge on the Ebb Tide only.*

The standard may be formulated thus—the aeration of a sample of mixed sewage and tidal water collected at the commencement of the fourth hour of the ebb of an average tide in calm dry weather at any point 200 yards from the outfall, or of a sample of the sewage when mixed with tidal water in proportion of the ascertained diluting power of the latter at the given distance when either is kept out of contact with theair for 48 hours at 18°C., shall not be less than 0·85 c.c. oxygen per litre, and the subsequent rate of absorption shall not exceed 0·055 c.c. oxygen per litre, per hour.

(*b*). *Discharge at all States of the Tide.*

The standard should be formulated similarly to the preceding one, except that the test sample should be collected at *low water* of an average tide.

Standards Required to meet Special Cases.

As already pointed out, the above standards would not form adequate protection against the growth of undesirable sea weeds, such as *ulva latissima*, which rapidly develope and spread in the presence of sewage matters, where the topographical conditions are also favourable. The conditions which conduce to the growth of these weeds have been made the subject of careful investigation by one of the authors (Letts), and it has been shown by him that it is the inorganic nitrogen constituents of sewage or of sewage effluents which encourages their growth. Hence, to avoid setting up favourable conditions, the sewage must be specially purified with the object of getting rid of its nitrogen compounds as far as possible. The results of this investigation has been summarised in another Section of this Report, entitled "Indirect Nuisances caused by Green Sea-weeds."

The above standards could not also be regarded as a sufficient protection from discolouration of the waters of health resorts. Crude sewage or sewage which has only been screened and settled, even in very small proportions, exerts a very decided discolouring effect in the waters into which they are discharged. Hence, only good sewage effluents from filter beds or from land treatment should be allowed to be discharged in their neighbourhood.

PART XIII.

The Aeration Method of Analysis.

The method which has been employed for studying the chemical changes which have been described in the earlier parts of this Section, may also be employed for the exact analysis of polluted waters, and it has been termed the Aeration Method, to distinguish it from other methods of water analysis.

The principles underlying the method, and the results obtainable by it, have already been amply indicated, and it is only necessary here to give some practical details of its working and descriptions of the special apparatus required for it.

The provision of a sufficient store of oxygen for the complete fermentation may be effected, as already indicated, in two different ways, the selection of one or other depending upon the strength of the polluted water, and the nature of the information required concerning it.

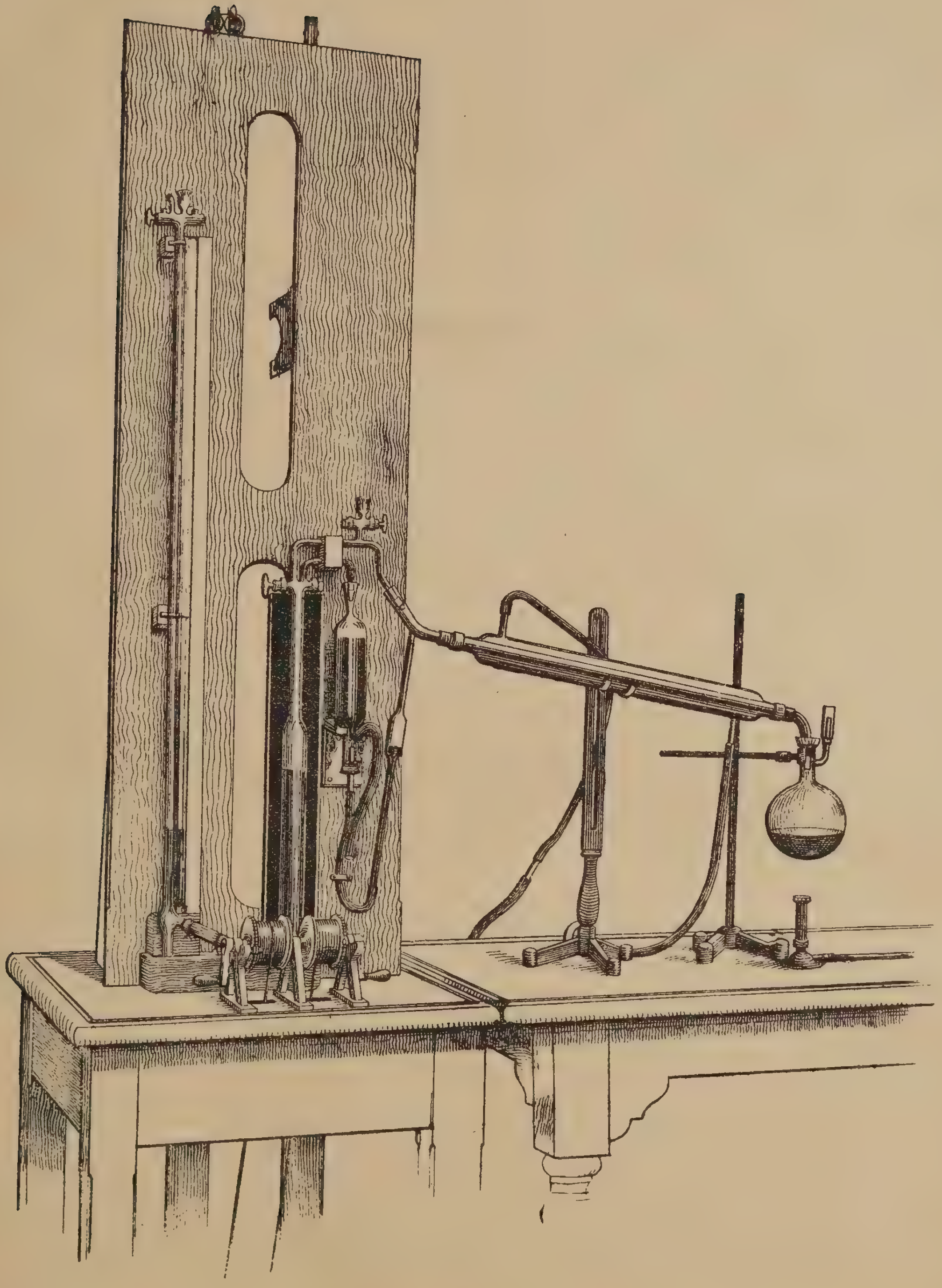


FIG. 7. ADENEY'S APPARATUS FOR THE EXTRACTION AND ANALYSIS OF GASES DISSOLVED IN WATER.

Weller & Graham, Ltd Litho. London.

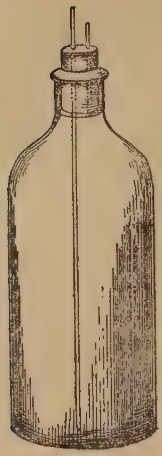


FIG. 1.

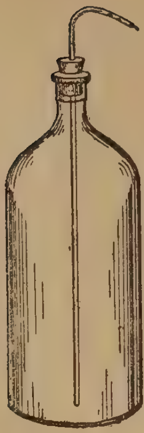


FIG. 2.

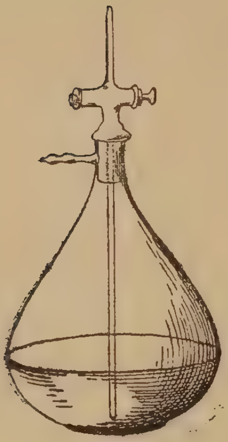
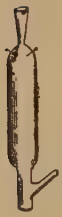
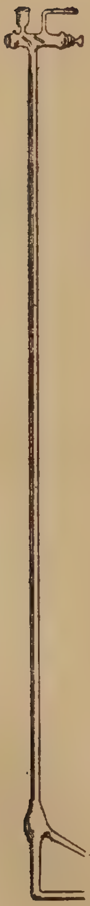


FIG. 3.



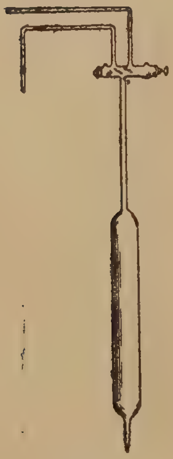
Laboratory Vessel.

FIG. 6.



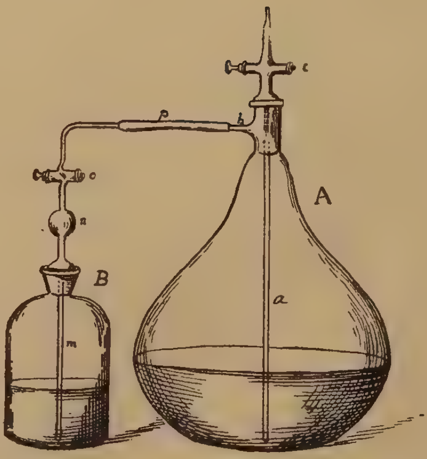
Pressure Tube.

FIG. 5.



Burette.

FIG. 4.



Adeney's Apparatus for the Rapid Determination of the Rate of Absorption of Oxygen during Fermentation in Polluted Waters.

FIG. 8.

(1.) The sample may be diluted with good tap or sea water, in sufficient proportion to ensure that the dissolved oxygen in the latter shall be in excess of that required for the fermentation of the polluting matters.

(2.) A known volume of the polluted water may be enclosed in a suitable bottle or flask, with a known and sufficient volume of air.

When providing for the required supply of oxygen by dilution, the sample may be mixed with tap or sea water in the proportion of 1 to 10 per cent., according to the strength of the polluted water. Portions of the mixture, about 1,000 cc. each, are transferred into well-stoppered bottles, and these, after being completely filled and securely closed, are immersed neck downwards in distilled water, and kept out of contact with air for the required length of time. At the same time the dissolved gases and ammonia and nitric and nitrous nitrogen, if present, are determined in another portion of the mixture.

When provision for a sufficient supply of oxygen is made by enclosing a portion of the sample with air in a flask or bottle, convenient volumes of the former will be found to be from 200 cc. to 900 cc., according to its strength, with from 800 cc. to 100 cc., of the latter, or the volumes may be in these proportions, respectively, if it be desired to employ larger quantities.

When air is left in the fermentation flask, Fig. 3, to provide a supply of oxygen, its volume can, at any time, be easily and accurately determined in the following way:—

The flask is immersed in a water bath, kept at a constant temperature. It is connected by means of a capillary rubber tube with one of the branch tubes of the gas burette of the gas apparatus shown in Fig. 7 and to be subsequently described, and a portion of the gas in it is drawn into the burette, the water jacket of which is kept at the same temperature as the water bath in which the fermentation flask is immersed. While the stopcocks are still open, the volume of the gas in the burette is noted, and also the temperature and pressure. The mercury reservoir of the burette is then lowered to draw more gas into the burette, and the volume in the latter is again noted, together with the pressure and temperature. The data thus obtained afford the means of calculating the volume of the gases in the fermentation flask. Thus:—

Let x = the volume of the gases in the fermentation flask at the temperature of the water bath.

a = the volume of gases first observed in the burette.

Then $x + a$ = the total volume of gas in the flask, connecting tube and burette at pressure p.

Let b = the volume of gas next observed in the burette,

Then $x + b$ = total volume of gases in flask, connecting tube and burette at pressure p^1.

$$\text{Then } \frac{x + a}{x + b} = \frac{p^1}{p}$$

The total mass of the gas in the flask is therefore known, since it is equivalent to a known volume $x + a$ at a known pressure, p, and temperature, t. The volume of the gas at 0°C., and 760 mm., bar., can be calculated in the ordinary way.

The necessary connection between the fermentation flask and gas burette can be made air-free without difficulty, by filling the branch tube of the burette and the attached rubber tube with mercury, and closing the latter by a screw clip fixed about 1½ inch above its free end. When this free end is required to be attached to the flask, it is filled with mercury or water; the rubber can then be passed over the glass tube in a manner to exclude every trace of air.

It need scarcely be pointed out that the analysis of the gases contained in the atmosphere of the fermentation flask can easily be effected by drawing a small portion into the gas burette and, after measuring them, submitting them successively to the action of potash, and of potash and pyro-gallic acid, in the ordinary way, to determine the carbon dioxide and oxygen directly, and the nitrogen indirectly, by difference. It will be found convenient to employ gas absorption pipettes, of the simple form used by Stead in his gas-analysis apparatus for the purpose, They can, without difficulty, be successively attached to the gas burette by means of a capillary rubber tube.

Special Apparatus Required for the Aeration Method.

1. *The Collection of Samples.*

For collecting samples a strong glass bottle of the capacity of about three litres is employed. It is fitted with an indiarubber cork through which two glass tubes are fitted, as shown in Figure 1. When samples from below the surface of the water are required, the bottle is firmly attached to a sounding chain, which is provided with a sufficiently heavy sinker, and rapidly dropped to the bottom of the water, or to the required depth below its surface. When full it is drawn up, and an indiarubber tube is attached to each of the outer ends of the glass tubes fitted to the cork. By their means the water from the collecting bottle can be syphoned out into a smaller one, about 1,000 c.c. capacity. If this latter bottle be completely filled, and the water be allowed to overflow a little, it may be filled with water which has not come in contact with the air to an extent sufficient appreciably to affect its aeration. The bottle is closed by means of an indiarubber cork, which is fitted with a capillary glass tube long enough, when in position, to reach nearly to the bottom of the bottle. To the outer end of this tube is attached a short length of thin walled indiarubber tubing, which is plugged by a piece of solid glass rod and thereby closed, as shown in Figure 2. With a little care on putting the tube and cork into the mouth of the bottle, in the act of closing it, the water can be made to rise up through the capillary tube to the indiarubber tube, and completely to fill it; the tube is then gently compressed and closed by the glass rod stopper. The tube can then act as a valve, and allows of slight contractions or expansions of the contents of the bottle, with alteration of their temperature.

By the simple means here described, satisfactory samples may be collected from a tidal water, and transferred to suitable bottles for preserving them out of contact with the air during conveyance to the laboratory.

2. *The Fermentation of Samples.*

Ordinary bottles, about 800 cc. capacity, with well-ground stoppers, will be found suitable for preserving the samples out of contact with the air, during fermentation, when the dilution method is employed. The bottles are completely filled with the sample, and kept neck downwards immersed in distilled water, which is contained in sufficiently large glass jars. These latter are covered with glass plates to prevent the evaporation of the water, and to protect it from the dust.

When air has to be enclosed with a sample of water, a flask of the form shown in Figure 3 is convenient. It is similar in construction to Chancel's flask for taking the specific gravities of gases. It consists of a flask, the neck of which is ground and fitted with a hollow glass stopper. A side tubule, 1 mm. bore, is fused on the outside of the neck, and a hole is bored through the side of the stopper to correspond with it. In one position of the stopper, the outer tubule may be placed in direct communication with the interior of the flask. The outer end of the stopper is continued into a glass capillary tube furnished with a stopcock; this tube is continued on the inside of the stopper by a tube 4 mm. bore, which reaches nearly to the bottom of the flask, when the stopper is in position. With this form of flask, the gases in the air space, at the conclusion of the experiment, may easily be measured as already described, and a portion transferred to the special gas analysis apparatus, which we shall next describe, for analysis. The water may then be transferred to the same apparatus, and the dissolved gases in it boiled out in vacuo, and analysed.

Instead of these flasks, ordinary bottles closed with rubber corks fitted with capillary glass inlet and outlet tubes, will do. The rubber corks have been found by experience to exert no appreciable effect upon the fermentation of the water. The exterior ends of these capillary tubes are closed by means of short pieces of capillary rubber tubing plugged with pieces of solid glass rod. The rubber corks and tubing should be coated with an alcoholic solution of shellac to prevent diffusion through them.

3. *Adeney's Apparatus for the Extraction and Analysis of the Gases dissolved in Water.*

This apparatus consists of a gas burette enclosed in a glass cylinder, a pressure tube, a laboratory vessel, and a laboratory flask with an intermediate condenser. The first three are shown in Figures 4, 5, and 6, respectively. The way in which they are fitted together and supported will be understood from Figure 7.*

The upper end of the burette is closed by a Friedrich's two-way stopcock, by means of which communication can be opened or closed between it and the laboratory vessel or laboratory flask, through the two branches which spring from the upper side of the stopcock. The branch to the laboratory vessel is a capillary tube, and that to the flask is of wider bore, 2 or 3 mm.

The lower portion of the burette is contracted and passes through a hole cut in the centre of the rubber bung, which closes the lower end of the glass cylinder surrounding the burette. It is then bent at right angles and connected by rubber tubing with the similarly bent end of the pressure tube.

The upper contracted portion of the burette is about 225 m.m. long, and has a capacity of 15 cc.; the wider portion is about 410 mm. long, with a capacity of a little more than 250 cc. Both portions are graduated, the former in $\frac{1}{10}$ cc., and the latter at intervals of 25 cc.

The pressure tube has a working length of 1,000 mm. above the level of the lowest division of the burette. Its upper end is also closed by a Friedrich's stopcock.

The supply of mercury to the burette and pressure tube is regulated by means of a reservoir which can be moved vertically up and down at the back of the apparatus by a catgut line passing over the necessary pulleys to a windlass in front of the apparatus as shown in the drawing. The flexible tube from the reservoir is attached to a side branch fused to the lower portion of the pressure tube.

The height of the mercury in the pressure tube is read by means of a millimetre scale etched on the unsilvered surface of a narrow slip of looking-glass that is fixed at the back of, and close to, the pressure tube, at an angle to reflect the image of the tube through the portion of the glass bearing the sacle.

The laboratory vessel differs in principle and shape from that used in Frankland's and Macleod's apparatus. Its shape is indicated in the drawing, Figure 6. The lower contracted portion is 25 mm. diameter and 55 mm. long; it is furnished with a branch tube for connecting the vessel with a second mercury reservoir, which can be drawn up and down by a catgut line and a second windlass in a similar manner to the one connected with the pressure tube. The middle portion is 160 mm. long, and the upper end is first contracted and then expanded to a funnel shape; it is 55 mm. long and the diameter increases from 3 or 4 mm. to 20 mm. at the mouth. Two platinum wires are sealed in the sides of the vessel for explosions.

The funnel shape of the upper portion of the laboratory vessel enables it to be easily connected with, or disconnected from, the branch tube of the burette. The end of this tube is fitted with a rubber collar, and when the vessel is placed in position the collar fits into the funnel and tightly closes it. The laboratory vessel is at the same time supported by a horseshoe-shaped bracket in the manner shown by the drawing. If the space above the rubber collar be filled with mercury a perfectly air-tight joint is obtained, and a vacuum can be maintained, or explosions may be made in it under low pressures without fear of loss.

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* The apparatus can be obtained from Messrs. Baird & Tatlock, London.

To disconnect the laboratory vessel, the lower end is drawn forward sufficiently to clear the shelf, and it is then lowered to detach it from the branch tube. By reversing these movements the laboratory vessel may again be placed in position.

The lower end of the vessel is closed by a rubber cork, and in order to provide the means of introducing gaseous or liquid re-agents into the vessel, a glass capillary tube, about 100 m.m. long, is fitted through the cork; the outer end of this tube is closed by a piece of capillary rubber tubing and a small screw clamp.

The method of working the apparatus is as follows :—

The burette, pressure tube, and laboratory vessel are filled with mercury. The laboratory flask, which has a capacity of about 1,600 c.c., is fitted to the end of the condenser as shown in the drawing, 50 c.c. of distilled water, and generally a little sulphuric acid, having been previously put into the flask. The water in the flask is then boiled, the air and steam escaping through the side tube in the neck of the flask. The boiling is continued for a few minutes, the burner is then removed, and at the same time the side tube is closed by a piece of rubber tubing and glass rod. The air still remaining in the flask is exhausted by working the burette and its reservoir as a Topler pump. As air is drawn from the laboratory flask into the burette at each down stroke of the reservoir, it is expelled by the up stroke into the laboratory vessel, or into the open air. After the flask has been completely exhausted, the laboratory vessel is disconnected from the branch tube, and the gases from a fermentation flask, or a known volume of the water to be examined, is drawn into the burette, and then allowed to flow into the flask. To effect this the rubber collar is detached from the end of the branch tube, and the latter is connected with a piece of capillary rubber tubing. This is carefully filled with mercury, and its lower end is then immersed in the water for examination, the burette reservoir is lowered a little, the stopcock opened and the water then passes into the burette. By gradually lowering the reservoir, 200 c.c., or a less volume, may be drawn into the burette, and thence transferred to the laboratory flask. The laboratory vessel is replaced in position and reconnected with the branch tube. The water is boiled and the gases are drawn into the burette and expelled into the laboratory vessel for storage. After the gases have been completely extracted they are measured and analysed, the absorptions (and explosions when necessary), being carried out in the laboratory vessel.

When the gases in the atmosphere of a fermentation bottle or flask are required to be measured and analysed, the transference of a portion of them presents no difficulty. The connection with the branch of the gas burette to the side tubule of the fermentation flask may be made in the manner already described.

When, in the act of measuring the gas, the level of the mercury in the burette is being adjusted, the stopcock may be left open, and the adjustment be made by manipulating the two reservoirs. When all the gas has been transferred from the laboratory vessel to the burette, mercury, or more generally water—since a small quantity usually collects in the laboratory vessel during the operation of extracting the gases from the laboratory flask—rises a little in the capillary branch tube ; it will be found convenient to use this as an index in the measurement.

When the necessary adjustments have been made, the height of the mercury in the pressure tube is read. The stopcock is closed and a small quantity of a solution of potassium hydrate is introduced into the laboratory vessel thus :—The reservoir of the laboratory vessel is adjusted at a level well above that of the reagent tube, and a pipette containing the solution of potassium hydrate is connected to the free end of the rubber tube attached to the reagent tube. On unscrewing the clamp the mercury will flow into the pipette, and expel any small bubble of air that may have been left in the open end of the rubber tube after attaching the pipette to it. The clamp is screwed up again, and the reservoir is dropped to a level a little below that of the reagent tube. On carefully opening the clamp again the mercury will flow back into the laboratory vessel, and after it the required amount of potash solution. The clamp is again closed and the reservoir raised to its former level. To effect the absorption of the carbon dioxide by the potash, the gas is passed into the laboratory vessel, and backwards and forwards into the burette three or four times. The remaining gas is measured as before at the same volume.

If the volume of carbon dioxide has been large, it will reduce the errors in the further process of the analysis, if the remaining measurements be made at a less volume. They should in fact be made at as small a volume as possible. The operation of absorbing the oxygen by means of pyrogallic acid is carried on similarly to that for absorbing the carbon dioxide. The remaining gas will in most cases consist of nitrogen. Its pressure at the volume at which the measurements for the oxygen were made is easily determined by deducting from the last noted pressure, the height of mercury in the pressure tube corresponding to the height of mercury in the burette at the graduation at which the measurements for the oxygen were made. It is advisable to make this for each experiment by noting the height of mercury in the pressure tube which corresponds to the height of the mercury in the burette, when adjusted at the same graduation mark in vacuo.

The residual gas, after the absorption of the carbon dioxide and oxygen, may in some cases contain either hydrogen or marsh gas, or both. When they are suspected, the residual gases are transferred to the laboratory flask and the laboratory vessel, and the burette are very carefully washed first by means of sulphuric acid, and then by water. These latter are introduced into the laboratory vessel similarly to the absorption reagents.

After the operation of washing has been completed, the liquid in the laboratory flask is boiled, and the gases drawn from it into the burette and stored in the laboratory vessel. When they have been measured, some pure oxygen is introduced into the laboratory vessel in the same manner as the reagent. The mixed gases are then measured and exploded under reduced pressure, and the further operations of the analysis proceeded with in the ordinary way.

A very useful lubricant for the stopcock of the gas burette, and for those of the special flasks employed for enclosing the samples of water during fermentation, and one which does not undergo fermentation, can be prepared by heating three parts of pure vaseline and one part of black rubber until all are thoroughly incorporated together. It was suggested to the author of the method by Sir W. Ramsay, K.C.B.

It has been stated that in preparing the apparatus for the extraction of the dissolved gases in a sample of water, a little water, and generally a little sulphuric acid, is put into the laboratory flask at the commencement. The occasions when sulphuric acid must not be so added arise when nitrites are present. Distilled water only is then put into the flask, with the result that, when the sample of water is transferred to it, the dissolved oxygen and nitrogen are completely extracted, and a portion only of the carbon dioxide. These are transferred to the laboratory vessel, measured and analysed. The laboratory vessel and burette are then carefully washed in the manner above described, and a small quantity of freshly mixed distilled water and pure concentrated sulphuric acid is drawn into the burette, and thence transferred to the laboratory flask, when the remaining carbon dioxide can be extracted and determined.

The time required for the extraction and analysis of the dissolved gases in a sample of water is about one hour, including washing out the apparatus; when nitrites are present, one and a half hour will be required; and when marsh gas and hydrogen are present, the time required will be about three hours.

A Simple Modification of the Aeration Method for the Rapid Determination of the Rate and Total Volume of Oxygen absorbed during the Fermentation of the Organic Matters in Polluted Waters.

For the purposes of general analysis, the dilution method for providing a sufficient supply of oxygen for fermentation is quite unsuitable, owing to the very slow rate at which fermentation proceeds in very weak solutions of organic substances.

To ensure as rapid a rate of fermentation as practically allowable, an excess of air should be provided, and the polluted water should not be diluted except when it is as strong as ordinary sewage, when it may be diluted with five to ten times its volume of tap or sea water. A good guide for deciding a suitable dilution for a sample of fresh sewage or tank liquor, is the quantity of free ammonia it contains. It should be diluted to reduce the ammonia to about 0·5 parts per 100,000.

When dealing with effluents from filter beds or land treatment, it is unnecessary and undesirable to dilute them.

If the fermentation flask containing the sample and a sufficient supply of air can be put into a mechanical shaker, and the sample be kept in gentle and constant motion, there appears to be, from a few experiments made by the author of the method, no need to dilute even the strongest sewage.

The experiments referred to are recorded in the appended table. A sample of exceedingly offensive septic tank liquor of quite exceptional strength was employed for them. Several portions of the sample were enclosed, each with a sufficient supply of air in a fermentation flask, and one was examined every twenty-four hours for the first four days, then on the eighth day, and finally on the twelfth day. After the first twenty-four hours all odour of offensive putrefaction had disappeared, leaving the liquid with the odour of ordinary fresh sewage; this continued during the second and third day. On the eighth day all odour of sewage had disappeared; at the same time the turbidity had nearly disappeared. On the twelfth day it had entirely disappeared, and nitrification had set in.

The rate of absorption of oxygen in these experiments, and the ratio of carbon dioxide formed to the oxygen absorbed, during the carbon fermentation in the sample of tank liquor, are shown by the two accompanying curves.

TABLE 39.—Experiments showing the Rate and Duration of the Carbon Fermentation in an exceptionally strong Sample of Septic Tank Liquor, when kept constantly and gently shaken in contact with an Excess of Air, at Temperatures varying between 16 and 19°C. (Adeney).

The following experiments were made:—

(1). The dissolved gases, and ammonia, were first determined in a portion of the sample.
(2). Another portion of known volume was enclosed in a fermentation flask with a known volume of air, and gently and constantly shaken for 24 hours, when both liquor and air were analysed.
(3). Another portion was similarly enclosed and kept for 48 hours, and analysed.
(4). Another portion similarly enclosed and kept for 72 hours.
(5). Another portion kept for 96 hours.
(6). Another portion kept for 192 hours.
(7). Another portion kept for 288 hours.

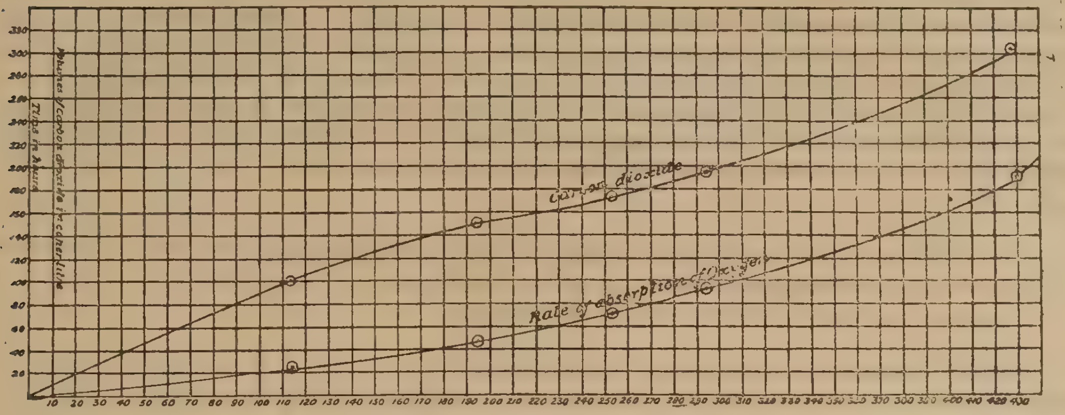
Experiment.	Gaseous constituents expressed as volumes 0°C., and 760 m.m. Bar., per 1,000 volumes of water.									
	Dissolved Gases.			Atmosphere in flasks.					Nitrogen as ammonia.*	Remarks.
				After fermentation.			Before fermentation.			
	Carbon dioxide.	Oxygen	Nitrogen.	Carbon dioxide.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.		
1	262·04	0·0	20·69†	–	–	–	–	–	15·0	Offensive putrefactive odour
2	331·75	0·0	13·70	30·45	3·38	445·63	116·38	437·83	15·0	Odour of fresh sewage.
3	337·95	0·25	14·15	75·29	30·60	861·20	224·38	844·13	15·0	Ditto.
4	347·84	0·31	13·56	90·92	57·44	1184·55	309·08	1162·7	16·0	Ditto.
5	360·19	0·40	13·47	98·45	143·45	1655·60	433·18	1629·5	17·0	Free from odour, turbidity much reduced.
6	387·06	2·0	13·28	192·76	178·24	2308·59	607·48	2285·3	18·0	Free from odour, turbidity slight.
7	–	–	–	235·92	356·29	3145·78	828·20	3115·6	18·0	Odour of garden soil, quite clear, brown tint; much sediment of a flocculent character. ‡

* Expressed in parts per 100,000.

† This volume possibly includes hydrogen and marsh gas.

‡ ·03 grm. nitrous nitrogen was found in the liquid at this stage, showing that nitrification had already set in. No nitrates nor nitrites were found in the preceding experiment.

Curves showing the Rate of Absorption of Oxygen by a Sample of Septic Tank Liquor, when kept in constant gentle motion in contact with air, in c.c. per litre per hour, and the Volumes of Carbon Dioxide formed and of Oxygen absorbed, during the fermentation of the Organic Matters therein.



Volumes of Oxygen in cc. per Litre.

In a complete analysis by the aeration method, determinations of the dissolved gases, of the gases in the atmosphere of the fermentation flasks, and of ammonia, and of nitrous and nitric acids, if present, are necessary, both before and after complete fermentation, and during intermediate steps, if the rate of absorption of oxygen and attendant changes during intermediate steps of the fermentation be required to be known.

It is obvious, however, from the experiments just quoted that in ordinary routine analysis, all these determinations are not needed. For most practical purposes, it is only necessary to determine the rate and total absorption of oxygen, and the character of the fermentation, whether a carbon or nitrogen one. The first can be done by estimating the loss of oxygen in the atmosphere of the flasks, and the second by ascertaining whether nitrates or nitrites have been formed or not. In most cases, however, even this will be found unnecessary, as the completion of the carbon-oxidation stage of fermentation will be indicated by the cessation of the absorption of oxygen which occurs during the interval of rest which occurs before the commencement of the nitrogen-oxidation stage.

Figure 8 shows the apparatus employed by the author of the aeration method for this purpose.

It consists of a fermentation flask A, already described (Fig. 3), which is connected by a rubber tube to a second but smaller flask B. The construction of both flasks and method of attachment will be understood from Fig. 8. The capacity of the fermentation flask is about 1,000 c.c., and that of flask B about 200 to 500 c.c. The stopper of B is of glass, and the tube *m* which is fitted to it is about 4 mm. bore; the bulb *n* just below the stopcock *o* is about 5 c.c. capacity. A small hole is bored through the neck of the flask, and one corresponding to it through the stopper, in order to provide the means of connecting the air in the flask with the air outside, when necessary.

The method of employing these flasks is as follows :—A known volume of the polluted water is placed in the flask A, together with a little magnesium hydrate to fix the carbon dioxide. The stopper is then inserted, so that the outer tubule *b* is in communication with the atmosphere of the flask, and the stopcock *c* is open. Distilled water is put into the flask B in such quantity that it shall, roughly, have the same proportion to the air-space left that the volume of the polluted water bears to the air-space in A. The stopper is then inserted so as to leave the hole in the neck coinciding with that in the stopper and the plug of the stopcock *o* removed. The two flasks are now connected by a capillary rubber tube *p*. The whole apparatus is allowed to stand for a few minutes until the contents of the two flasks have a similar temperature. This is noted, as also the barometric pressure. The stopcocks are then closed and the stoppers of the two flasks are turned so as to close them also. The two attached flasks are put into a mechanical shaker and their contents kept gently shaken for the period of time during which it is desired to observe the rate of absorption of oxygen by the polluted water.

While the shaking is proceeding, the gas apparatus (Fig. 7) may be prepared for the subsequent operations. The two branch tubes of the burette are detached from the condenser and laboratory vessel, which are shown in Fig. 7; to one branch is attached a short length of capillary rubber tubing, and to the other is attached, also by a capillary rubber tube, a reservoir of oxygen standing over mercury. About 200 c.c. of oxygen are drawn from it into the burette, and a little of the gas is expelled from the burette through the other branch and attached rubber tube, the open end of which is held under water, until the air in both branch and rubber tubes is considerd to have been displaced by oxygen; the stopcock of the burette is then closed and the rubber tube while still dipping under water is also closed by a screw clip which is fixed to it about 1½ inch from the free end.

The volume of oxygen in the burette is then noted, together with the temperature and pressure. The pressure is then altered a little if necessary so that it shall be a few millimetres of mercury below that of the atmosphere.

At the expiration of the period of shaking, the flasks A and B are taken out of the shaker, and A is connected to the gas burette by slipping the free end of the rubber tube attached to the branch tube over its stopcock *c*. When this has been done the screw clip is unscrewed, and the stopcock is opened, and finally the stopcock of the burette. Oxygen then passes from the burette into the flask to take the place of that which has been absorbed by the polluted water in it. When the gas ceases to pass in, the stopper of B is turned, and the stopcock *o* is cautiously opened, when the water in the flask B will rise up the tube *m* into the bulb *n*, and the mercury reservoir of the gas burette must be cautiously raised until the water in the bulb *n* is slowly driven back and returns to its former height in the tube *m*. When this has been accomplished, the pressure of the gases in the flask A will be the same as at the commencement of the experiment. All stopcocks are now closed and the clip of the rubber connecting tube is screwed up. The flasks A and B can then be detached from it and returned to the shaker. The pressure and temperature of the residual gas in the burette, when at its original volume, are then carefully read and noted. When the volumes of oxygen in the burette before and after the operation of replenishing the absorbed gas in the flask A has been reduced to 0°C. and 760 mm. bar., the difference between them will give the volume of oxygen which was absorbed by the given volume of the polluted water during the period of shaking.

These operations may be repeated as often as necessary. The volumes of oxygen absorbed can be plotted against the time taken for absorption, and a curve will be obtained showing the rate of absorption of oxygen in c.c. per litre of the water, per hour.

On reflection, it will be seen that approximate results, sufficiently accurate for many purposes, could be obtained by a slight modification of the above operations. The volume of oxygen absorbed by the polluting water at any time could be accurately ascertained, if, instead of attaching the flask A to the gas burette, it be connected to an ordinary burette filled with distilled water. The volume of oxygen absorbed in the fermentation flask would then be indicated by the volume of water which would be required to take its place. The pressure equilibrium between the two flasks A and B could be readjusted to that obtaining at the commencement of the experiment by an operation similar to the one just described, viz., by opening communication between them, and carefully raising the burette until the height of water inside and outside the tube *m* in the flask B was the same.

The loss of water in the burette would then equal the volume of oxygen absorbed in A at the temperature and pressure obtaining at the commencement of the experiment.

It is obvious that this modification is open to certain inaccuracies unless they be guarded against. For example, the act of replacing the absorbed oxygen from the atmosphere of the flask by water is equivalent to increasing the pressure of the nitrogen of the same atmosphere, to a degree more or less decidedly above that at the commencement of the experiment, and this would lead to an absorption of atmospheric nitrogen by the polluted water in the flask A, and by the distilled water added to it, and the error arising therefrom would become considerable unless the air in the flask were present in large excess, and the volume of oxygen absorbed only a small fraction of that present in the air.

The addition of water to take the place of the oxygen as it is absorbed would also gradually lead to a reduction in the store of that gas in the atmosphere of the flask to an extent that would appreciably reduce the rate of fermentation in the polluted water. This source of error would, however, also be inappreciable so long as the air in the flask was largely in excess of the polluting matters in the water. Sufficient excess of air will always be secured, if the proportions of it and of the polluted water in the fermentation flask be regulated in accordance with the proportions already given on p. 97.

If the polluted water be not strong, *e.g.*, a good effluent, or if it be strong, *e.g.*, a septic tank liquor, it be diluted sufficiently to reduce the free ammonia to about 0·5 part per 100,000, it will usually be found unnecessary to keep it constantly shaken with air in the flash. It will be sufficient to occasionally shake the flask.

India-rubber, instead of glass, stoppers may be used for the flasks A and B. They should be coated with shellac varnish to prevent diffusion of gases through them.

PART XIV.

GENERAL SUMMARY.

In the foregoing pages the chemical changes, which occur in a polluted water during so-called self-purification under aerobic conditions, and the laws underlying them, have been traced and established; and this has necessitated the discussion in minute detail of a large amount of experimental evidence of a varied character. A brief summary of the results arrived at, apart from experimental details, may therefore prove of some convenience to those interested in the subject.

The most important change which occurs in an unpolluted water, when it is mixed with sewage or other water-borne refuse matters, is the more or less rapid absorption of its dissolved oxygen.

The absorption may be effected in three different ways:—(1) The polluted water, from its own state of total or comparative de-aeration, reduces the aeration of the unpolluted water by simple dilution; (2) the polluted water may contain directly and easily oxidisable substances, which on becoming mixed with the unpolluted water will cause a more or less rapid loss of its dissolved oxygen; (3) the organic constituents of the sewage, which are not directly oxidisable (and they usually form the greater portion of the organic substances in it), and the ammonium compounds, are oxidised through the agency of water bacteria, and thus indirectly cause a loss of dissolved oxygen.

These possible causes of de-aeration are enumerated in the order in which they would in all probability take effect under natural conditions. The first is obvious, although its importance has not been sufficiently recognised. Its effect can easily be differentiated from the other two, if the amount of dissolved oxygen, or as it is generally termed, the degree of aeration of the polluted water, be first determined, and this can be done without difficulty either by a gasometric or volumetric method.

The second cause of de-aeration is equally obvious, although its importance has also not been sufficiently realized. Such experiments as those recorded in Tables 34, 35, 35A, 36 and 37 prove that directly oxidisable bodies, from the rapidity with which they absorb oxygen, constitute a greater danger to the aeration of the water with which they become mixed than do indirectly oxidisable substances. Hence it is necessary to know the rate of absorption of oxygen caused by them as well as by indirectly oxidisable substances.

It is impossible to foretell the influence of these two causes of de-aeration from any information derivable from the ordinary methods of chemical analysis. It is, however, possible to do so by means of the aeration method, and the foregoing pages have been largely devoted to a description of that method, and of the experimental investigation upon which it is based.

A study of indirect oxidation by this method has shown that it is a physiological process analogous to the respiratory process of higher vegetable systems; but that it is only one, although the principal one, of a number of physiological processes concerned in the self-purification of a polluted water under aerobic conditions (pp. 21–23).

It is unnecessary to discuss these in detail. It is sufficient for the study of polluted waters to recognise the possibility of processes of digestion (by enzymes), and to regard the remainder as together exercising one function, viz., the synthesis of the constructive materials required for the growth and multiplication of the bacteria, and at the same time to remember that there must result from these synthetical processes waste or by-products, which may be regarded as excretory substances.

The chemical changes which are produced by the above processes may collectively be termed fermentative changes for convenience of reference.

Experiments with samples of sewage and of polluted waters, of various descriptions, have been made (pp. 28–30, 70–74), and it has been found that when they were severally mixed with unpolluted water in small proportions, within the limits of fouling, the fermentative changes which follow exhibit a definite and regular sequence. The organic matters first suffer complete fermentation, the products of change being carbonic acid, water, ammonia, and organic substances possessing the chemical and physical properties of the humus of cultivated soils, and of the organic substances to be found in all unpolluted natural waters, especially in those from upland surfaces.

A second stage of change subsequently ensues, in which these humus matters and the ammonium compounds are further fermented, the resulting products being carbonic acid, nitric acid and water.

The inorganic products of the first stage of fermentation result from the action of the respiratory process, and possibly also of enzymes; and the humus-like substances are waste products from the synthetical processes (pp. 21–23).

It is a point of interest to note that free nitrogen has not been observed amongst the products of the fermentation of organic substances in water under aerobic conditions, although it does undoubtedly occur amongst the products of fermentation in percolating filters even when the conditions therein are wholly aerobic. It is a question, no doubt, of intensity of oxidation. The filter presents conditions for an extremely rapid and intense oxidation; while water in large bulk, owing to the sparing solubility of oxygen in it, can only allow a sluggish oxidation to proceed in it.

Experiments with distilled water solutions of simple organic substances of known composition have shown that the respiratory process is one of simple oxidation, and that the organic matters affected by it are completely oxidised to the inorganic products, carbonic acid, ammonia and water. The oxidation may either be complete step by step as the fermentation proceeds, or only partial at first but finally complete, according to the chemical properties of the substances undergoing fermentation (pp. 13–21).

In the simple solutions employed in these experiments, it was evident from the composition of the organic substance dissolved in each, and from the ratio of the carbon dioxide formed to oxygen absorbed, on its complete fermentation, that the oxygen was almost, if not entirely, taken up by the respiratory process. Other experiments, however, have shown that it is quite possible, under certain exceptional conditions as to the composition of the fermenting substances, for the synthetic processes to take up relatively considerable quantities of oxygen (pp. 39–40). Whether oxygen is or is not taken up by these processes appears to be a question of composition of the fermenting substance, as might be expected. In ordinary cases, however, of polluted waters, the composition of the polluting substances generally appears to be such that during their fermentation the absorption of oxygen is practically confined to the respiratory process.

Enzymic action is intimately associated with the respiratory process in the fermentation of many organic substances. The chemical changes induced by them are principally hydrolytic, and the products are generally simplifications of the original body; and these undergo further fermentative change. Only in the case of urea do they bring about a complete change to the ultimate products, carbon dioxide and ammonia.

Sometimes enzymic changes occur with almost explosive velocity; *e.g.*, asparagin (p. 17), when present in the fermenting water, is hydrolysed with extreme rapidity, the whole of it being converted into aspartic acid and ammonia at the very commencement of the fermentation, the hydrolysed product, aspartic acid, then undergoing complete fermentation.

In other cases, enzymic change may proceed extremely slowly, very much more so than the other fermentative changes which may be going on in the same water. Urea when present in some polluted waters is an example of this (pp. 14–15).

There are some other substances which may occur in polluted waters, *e.g.*, native albumins and fats, and which require to undergo enzymic change before they can be readily fermented by water bacteria.

The chemical changes which are brought about by the respiratory process and by enzymes may be regarded as yielding a continual supply of energy to the bacteria. They effect the complete oxidation of 70 to 80 per cent. of the organic substances originally present in the polluted water.

The new material resulting from the synthetical process accounts probably for about 5 per cent., or even less, and the waste products for the remaining 15 to 25 per cent.

As regards possible relationships between the volume of carbon dioxide formed to oxygen absorbed in a polluted water, it is obvious there can be no very definite one, especially when the water contains directly and easily oxidisable substances, *e.g.*, sulphides, etc., in addition to indirectly oxidisable ones. As a matter of fact, however, in the case of most waters polluted by fresh sewage, a fairly constant relationship has been observed, the ratio of carbon dioxide to oxygen being approximately as 1 : 1. If the sewage be putrefactive and contain sulphides, the ratio may be much less, *e.g.*, the ratio for the septic tank liquor employed for the experiments recorded in Table 39 is as 1 : 1·3.

After the completion of the fermentation of the organic matters, a second stage of change, as already noted, sets in, and during it the products of the first stage, that is, the ammonium compounds and the humus matters, undergo further fermentation. As a result the former are completely oxidised to nitric acid and the latter more or less completely to carbon dioxide and nitric acid. The point of interest and importance in this stage of fermentative changes is the influence of the humus matters on the oxidation of the ammonium compounds.

Laboratory experiments have shown that they not only accelerate the fermentative changes, but that their presence is necessary for the oxidation of the ammonium compounds to nitric acid. When they are entirely absent, the oxidation is not carried under ordinary conditions beyond nitrous acid.

When the ammonium compounds are present in slight excess of the humus matters, both may be completely fermented, the inorganic products being carbon dioxide, water and nitric acid.

The changes which humus matters may undergo when in excess of the ammonium compounds, appears to be very variable. For example, when fresh, a portion of their carbon is readily oxidised to carbon dioxide, and then if unassociated with compounds of ammonia, they cease to undergo much further change.

The volume of oxygen actually absorbed in the second stage of fermentation does not bear a constant ratio to the oxygen theoretically equivalent to the nitrous and nitric oxides formed. The volume may be greater than the theoretical, in the proportion of 10 : 8·14 (Table 19, Experiment 1 and 1*a*), if humus matters are wholly absent; or less, *e.g.*, 10 : 13·5 (Table 19, Experiment 2), if these are present in large quantities and are freshly formed.

Where, as in ordinary cases of polluted tidal waters, humus matters are unlikely to be present in any but small proportions, the volume of oxygen required for the oxidation of the ammonia to nitric acid can be calculated with sufficient accuracy from the equation:—

$$2\,NH_3 + 4\,O_2 = N_2O_5 + 3\,H_2O.$$

On comparing together the changes which progressively occur in the two stages of fermentation which have been described, it becomes evident that the oxidation of ammoniacal nitrogen to nitrous and nitric acids constitutes the central feature of the second stage, just as the oxidation of organic carbon to carbon dioxide constitutes the central feature of the first stage. It may be concluded, therefore, that the products nitrous and nitric acids of the one stage are the analogues of the product carbon dioxide of the other stage. The first stage of fermentation may consequently be termed the carbon-oxidation stage, and the second the nitrogen-oxidation stage. These terms have the advantage of emphasizing a fact which it is necessary to keep in mind in dealing with the subject of water pollution ; it is that the sequence of the chemical changes, which occur during self-purification under aerobic conditions, takes place in accordance with thermo-chemical principles.

A classification of the substances which may occur in polluted waters may be made, based on their behaviour towards the dissolved oxygen of the water, as follows :—

(1) Directly oxidisable substances.

(2) Indirectly oxidisable substances.

These latter may be further sub-divided, according to their fermentative properties into—

(*a*) Carbon oxidisable substances, that is, most known organic substances except antiseptics.

(*b*) Nitrogen fermentable substances, that is, the waste products from a first stage fermentation, and ammonium compounds.

Not only do the fermentative changes in a polluted water follow a definite and regular sequence, but the relationship between the oxygen absorbed and the products formed, and between both of these and the quantities of polluting matters originally present, are quantitative according to the following law :—The quantities of oxygen absorbed, and of products formed, on the completion of each stage of aerobic fermentation, is constant for similar volumes of the same polluted water, provided that the dissolved oxygen is in excess of the fermenting matters.

It must be granted from the above brief description of the fermentative changes which occur in a water during self-purification under aerobic conditions, that the significance of the presence of indirectly oxidisable substances in water depends not upon their exact quantity and chemical composition, but upon their fermentative properties and on the rate at which they will absorb oxygen from the waters with which they are mixed. The same remark applies with equal force to directly oxidisable substances.

It must also be granted that the methods which are at present employed for the analysis of sewage and of sewage effluents, and which were originally worked out for the analysis of potable waters, do not afford information of this kind. The aeration method has consequently been proposed for the purpose. As may be gathered from the perusal of pp. 67–91, it is possible to determine by its means the rate of absorption as well as the total absorption, of oxygen which a sewage or sewage effluent is capable of setting up when mixed in small proportions with unpolluted river or tidal water, during direct oxidation as well as during both stages of indirect oxidation. From the description of the method given on p. 96, it will be seen that several modifications in working can be adopted according to the object in view, that is to say, whether it be desired to study the fermentative changes step by step in their entirety, or simply to determine the rate of, or total, absorption of oxygen during them. The modification required for the latter purpose can be so simply operated that untrained persons can be taught to carry them out without difficulty.

Another phase of the subject of the self-purification of slightly polluted waters, and a scarcely less important one, is the rate at which the dissolved oxygen in such is replenished from the atmosphere under natural conditions, when it is being absorbed by polluting matters. It is obvious that definite information is required on this question before it will be possible to formulate standards of impurity for the protection of river and tidal waters from over pollution.

Experiments have been described (pp. 56-66) which afford some fairly trustworthy information on this subject. The results of these experiments were quite unexpected, since they show that the slow rate of re-aeration of large volumes of de-aerated tidal water under calm weather conditions, is not due to the slow process of mixing by thermal current or of diffusion of the dissolved gas after it has been taken up in solution by the surface layers of the waters exposed to the air. On the contrary, it has been shown that the slowness of re-aeration is due to retardation of the process of solution at the water's surface, and that when oxygen has become dissolved at the surface from the atmosphere, it is drawn with comparative speed through the water, apparently by some unexplained process of gravitational streaming. It has also been shown that long columns (6 feet) of de-aerated fresh or sea water enclosed in narrow glass tubes of small bore are comparatively quickly re-aerated when the surfaces of the columns were kept continuously broken, either by a mechanical stirrer or by a slow current of air delivered by an inlet tube dipping a little below the surface.

It has, furthermore, been found from these experiments that the aeration of the sea water columns was effected much more rapidly than that of the fresh water columns, and that the dissolved gases showed practically no tendency to accumulate in the surface layers of the sea water columns, but passed almost as quickly through them as they were dissolved, with the result that the degree of aeration of the water is found to be nearly uniform throughout the length of the column, if it be tested at different depths at any time during the process of aeration ; while in the case of the fresh water columns the dissolved gases did show a tendency to accumulate in the upper layers, and did not pass so rapidly to the lower layers.

From the data afforded by these experiments, it may be taken that the average rate of absorption of oxygen from the air is probably not less than 0·08 c.c. per litre per hour for sea water, and 0·03 for fresh water, at mean atmospheric temperatures. The rate for tidal waters varies between these two limits according to the proportions of sea and fresh water composing them ; thus it is probably about 0·055 c.c. per litre per hour for a tidal water consisting of equal parts of sea and river waters.

If these values be accepted, then any pollution of a tidal water of the given composition, which would not cause a greater rate of de-aeration than that equal to 0·055 c.c. oxygen per litre per hour, would exercise no apparent effect upon its aeration.

So far as present knowledge goes, it appears that the aeration of tidal water composed of equal proportions of fresh and sea water may be temporarily reduced to 3·45 c.c. oxygen per litre without fear of injury to fish.

The air saturation value at 18·0°C. for a tidal water of the composition above taken is 6·20 c.c. oxygen per litre. Hence an uniform and continuous absorption of dissolved oxygen, at the rate of 0·055 c.c. per litre per hour, and an additional temporary absorption of 2·7 c.c., may be allowed in such a water in calm weather at mean temperatures.

The period of time over which this temporary absorption may be required to be extended may be six and a quarter, twelve and a half, or forty-eight hours, according to the conditions attending the discharge of sewage, and according to the favourable situation or otherwise of the tidal water for the disposal of sewage.

The maximum quantities of sewage which may be discharged into tidal waters within these limits of de-aeration will be found discussed on pp. 67–91. Although no exact relationship can exist between the rates of absorption of dissolved oxygen and the percentage of sewage matters, in a polluted water owing the variable composition and fermentative characters of the latter, nevertheless it may generally be stated, from the experiments that have been described, that the dissolved oxygen in unpolluted tidal waters is generally not in danger of being completely absorbed in forty-eight hours if the waters be mixed with ordinary town sewage in proportions not greater than 5 per cent., provided the solid matters have been previously separated by simple subsidence, and provided that the sewage does not contain appreciable quantities of directly oxidisable substances.

Standards of impurity for the protection of tidal waters, and based upon the above considerations, will be found formulated in pp. 91–96.

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SECTION 2.

ON NUISANCES CAUSED DIRECTLY BY SEWAGE.

NUISANCES CAUSED DIRECTLY BY SEWAGE.

"Effluvium nuisances," as they may be termed, occur in certain tidal waters where the volume of sewage discharged into them is relatively large in proportion to the tideway itself.

This kind of nuisance may originate from a putrefying mixture of liquid sewage and water, but in the majority of cases we believe it to be due rather to foul deposits of sewage solids.

Evolution of sulphuretted hydrogen is, no doubt, the main cause of such nuisances, but the peculiarly fœtid smell often observed is in all probability due to other substances in addition.

A few of the more important localities where effluvium nuisances have occurred, or are still to be found, may be mentioned.

Glasgow, a city of more than 750,000 of population, formerly* discharged the whole of its sewage in an untreated condition into the Clyde, and the state of the river for several miles below the city was filthy in the extreme, the stench at low water, more especially in the summer, being almost intolerable.†

Carlisle, with a population of 40,000, also discharged its crude sewage into its river (the Eden), and the condition of that stream has been described as follows :— ‡

"The outfall of the sewer is about half a mile below the city, and the tide flows up within a mile of that. The whole of the way down to the outlet of the Eden is in the summer a mass of about 12–18 inches thick of filthy sludge at the bottom, with gas rising from it . . . . it is in a most loathsome state."

Barking Creek.—A tidal creek which goes from the Thames through Barking to Ilford, where a large quantity of sewage is cast into it, and complaints have been made chiefly in connection with nuisances arising from the smell, the latter being worst where the waters of the creek have received the sewage of about half a dozen different towns. Then the sewage of East Ham is backed up by the tide also as far as Barking Town, so that altogether the sewage of a population of about 200,000 passes through the town of Barking or is washed up to that town, and there a great deal of stagnation occurs with deposition of black mud. During the summer months there are continuous complaints of the odours given off by the mud and the river water, which probably at some times is more than half of it sewage or sewage effluent. §

River Lune.—The estuary of this river is without doubt very strongly affected by the sewage of Lancaster (population 40,000) and district, which passes into the river without any treatment, especially in the dry weather, when, according to the reports of the water bailiffs, it is nothing less than a cesspool. ¶

The Manchester Ship Canal.—Although this canal cannot be described exactly as an estuary, it is in a sense of a similar nature, and was visited by us during our tour of inspection of tidal waters in 1904. The condition of the water in the Manchester Docks (Throstle Nest Dock) is foul in the extreme, and we elsewhere describe it in detail (*see* p. 347).

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* A scheme for the treatment of the sewage of Glasgow (by chemical precipitation) was authorised in 1896–1898 and the works are still in progress.

† From personal observation in the summer of 1904 we should say that the condition of the river had not then been ameliorated.

‡ J. B. Slater, Roy. Comm. Salmon Fisheries Rep., 310–316.

§ Thresh. Interim Report: Royal Commission on Sewage Disposal, Vol. II. [Cd. 686], Q. 8839.

¶ Roy. Comm. Salmon Fisheries Reps., Appendix XXVI.; also Minutes of Evidence, 1070–1084, 1166, 1176, 1287–1289, 18918.

But we may here mention that it was entirely free from dissolved oxygen, black, stinking, and effervescing from the escape of foul gases.

In addition to the above localities it will be seen from the replies to the circular letter to the medical officers of health of certain tidal localities (*see* Appendix) that at *Devonport* the estuary is offensive and silting up, also that a neighbouring bathing place was closed owing to discoloration of water and accumulation of sewage. At *Plymouth* a nuisance has been caused by a deposit of sewage in Deadman's Bay and an annoyance at Millbay. At *Chatham* the foreshore is polluted in many places. At *Exmouth* there was formerly much nuisance before the outfall was carried further out into the channel. At *Rochester* nuisances are frequent from accumulations of sewage-polluted mud in the creeks and rills. And at *South Shields* one sewage outfall gives rise to much nuisance and a deposit of black offensive matter. Also that at *Cardiff* there is an occasional deposit of sewage on the river's bank and on the foreshore. At *Carnarvon* the mud deposits at the mouth of the river are to some extent impregnated with sewage. At *Blackpool* there is occasional nuisance and a slight sludge deposit. At *Southport* complaints have been made for a long time by the inhabitants of *Crossens*, a village a quarter of a mile from the sewer outlet, that sludge banks have been formed close to the sewer and along the adjoining channel. At *Stockton-on-Tees* bad odours are sometimes noticed, the mud deposited on the banks of the river no doubt containing sewage solids. At *Swansea* some complaints have been made, and sludge is said to be found opposite to the main outlet sewer. At *Hastings* occasional complaints of a smell have been made in connection with the western outfall; while at *Llandudno* complaints have been made as to floatable solids reaching the shore on flood tides. And at *Folkestone*, with the prevalent east and south-east winds, sewage is driven into the harbour and accumulates on the landing stages of the railway pier.

In Ireland the condition of the *Liffey* at *Dublin* is most filthy, the river being practically a cesspool at low water.*

The *Lagan* at *Belfast* before the main drainage scheme of 1889 was in almost as bad a condition as the Liffey, but at the present time its water is clear and quite free from smell (*see* pp. 229, 236).

In those estuaries which are navigable and into which crude sewage is poured in quantity, the removal of the submerged solids is necessary in order to keep the channel clear for shipping, and often considerable expense is incurred in consequence.

Thus at Belfast the harbour engineer stated† that, " Three or four years ago we actually dredged from the Victoria Channel between 30,000 and 40,000 tons of what was crude sewage, fœcal matter, which was as black as ink, and the stench from which was something terrible. That accumulation was going on for years, and is still going on, and is due no doubt to the discharge of solids into Belfast Lough. When I say that the 30,000 or 40,000 tons were removed at a cost of something like sixpence per ton, you can arrive at some estimate of the cost to the Harbour Commissioners."

In the case of Belfast, it may be added that the sewage outfall is situated at some distance (rather less than half a mile) from the dredged channel; the solids spoken of above by the late harbour engineer represent, therefore, only a small proportion of the actual sludge deposited in the Lough (*see* p. 230).

In other similarly situated towns the cost of dredging sewage solids must be considerable, but we have not been able to obtain any definite figures regarding the actual outlay.

On the assumption, however, (1) that the sewage contains 40 parts per 100,000 of solids in suspension, (2) a water supply of 30 gallons per head, and (3) that as dredged the solids contain 90 per cent. of water, calculation shows that 1,000 tons annually will be produced by a population of about 5,000. Applying these figures to the case of Glasgow, and for a rough estimate they no doubt suffice, and further assuming that the cost of dredging is sixpence per ton, the annual expenditure would amount to about £3,750.

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* The new main drainage scheme and purification works, now almost completed, will no doubt soon lead to an improvement in the condition of the river itself.

† Third Report of Royal Commission on Sewage Disposal, Vol. II. [Cd. 1487], *Giles*, Q. 13676.

Apart altogether from the nuisance caused by submerged sewage solids and the expense involved in removing them by dredging, they may prove troublesome and possibly dangerous in other ways even in the open sea. Thus a case has been mentioned of pier works within 500 yards of a sewage outfall from which crude sewage is discharged at all states of the tide. During calm weather the workmen when digging out the foundations never experienced inconvenience from the sewage, but after a storm they found the bottom of their trench filled with its débris.

The inference drawn by the engineer who reports this case, and who was conversant with the locality, was that about 200 yards or so out from the outfall a large bank of sewage mud collected under the water. It caused no nuisance and there was no sign whatever of it in the water, but during storms it moved away, because it was old and not fresh sewage that came into the trenches; and he adds that it opened his eyes to what he had not realised before, namely that within a few hundred yards of the shore an outfall that does not give any signs of surface pollution, or any signs whatever of pollution by putrescence, may be causing a deposit on the bed of the sea.*

A good deal of evidence has been given as to the effects on health of exposed mud banks in estuaries polluted by sewage.

Thresh† draws attention to the fact that, taking those districts going down the Thames in order, most typhoid is found where most mud is exposed. Towards Grays there is no mud. It is only below Canvey Island that the mud is exposed. Below Grays the typhoid fever rate increased enormously, and he quotes this rate for the districts of Rochford, Leigh, Southend and Shoeburyness—the three last of which at that time cast the whole of their sewage onto the foreshore, without any treatment whatever.

He also mentions Brightlingsea on the Colne estuary, where the untreated sewage was formerly discharged onto the foreshore, and there he found the typhoid rate higher than for the remainder of the county. Since treatment of the sewage has been adopted before discharging it, the number of cases of typhoid has diminished considerably.

Foulerton‡, in an investigation of the tidal Ouse (Hampshire), in relation to the prevalence of typhoid fever in the adjoining districts, and especially at Newhaven, situated at the mouth of the river, came to the conclusion that the river itself was responsible for this prevalence, as a consequence of the discharge of sewage containing the excreta of patients suffering from the disease into the upper reaches, and mainly at the town of Lewes.

"Regarding the polluted river then as the cause, one finds that the town (Newhaven) is exposed to the risk of infection in two ways: first, by the deposition of polluted sludge on the foreshore, which is exposed twice a day to the tide, and, secondly, by the pollution of the rather extensive mussel layings which are situated in the upper harbour.

"Of these two immediate sources of infection, I am inclined to regard the pollution of the foreshore generally as being by far the more serious."

Foulerton draws attention to the effects of tidal and non-tidal streams respectively on disease germs. In the case of non-tidal streams, not only does dilution come into action, but the organisms are deposited along with the suspended solid matters of the sewage on the bed of the stream. The disappearance of these disease-producing organisms is due to the fact that they are best adapted for growth in connection with some living organism, and so their environment at the bottom of the river is unfavourable for them. Therefore, in the struggle for existence between them and the bacteria naturally found in a good river water, the disease producers are at a heavy disadvantage, cease to multiply, and die out.

But in the case of a tidal stream the conditions are different. Here the disease-producing bacteria are deposited not only on the bed of the stream, but also on the mud or sludge on the banks and are uncovered at low tide.

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* Strachan. Interim Report of Royal Commission on Sewage Disposal, Vol. II. [Cd. 686], Q. 7650.

† Thresh. Interim Report of Royal Commission on Sewage Disposal, Vol. II. [Cd. 686].

‡ Report to the Sanitary Committee of the East Sussex County Council, 1903.

it now requires only the agency of a fly, feeding first on the organic matter in the sewage contaminated mud and then on some human food—milk, for instance—to convey the bacillus of typhoid fever from the river to some human being."

Williams,* while not liking to say exactly that the typhoid which occurs annually at Bridgend in South Wales is due to the foul condition of the Ogmore River, could not attribute it to anything else, the water supply and drainage being both good.

Belfast is a city in which typhoid fever is very prevalent, and formerly the whole of its sewage was discharged in the crude state into the Lough, where the tides are sluggish, and extensive mud and sand banks are exposed at low tide. These in the summer and autumn are as a rule in an exceedingly foul condition, owing to the masses of putrefying green seaweeds which have been cast ashore and give rise to an extensive nuisance (*see* Section 7A).

Undoubtedly many cases of typhoid have occurred among those living on the margin of the Lough within the polluted area (and notably on its southern shores, where the seaweed nuisance is most acute) which cannot be attributed to any such specific cause as a contaminated milk or water supply, defects in drainage, etc. These cases have frequently occurred among the better classes of the population who, as far as we have been able to ascertain, are not in the habit of eating locally gathered cockles, mussels, or periwinkles, and, as oysters are no longer dredged from the Lough, the possibility of the disease having been communicated by the consumption of contaminated shell-fish is highly improbable.

There seems good reason for the belief that emanations from sewage and no doubt from putrefying matters in general are detrimental to health, and induce vomiting, diarrhœa and prostration,† and that such emanations, even when largely diluted, may lead to minor ailments, such as headache, loss of appetite, and a general lowering of health. Thresh is of the opinion that the complaints of ill-health, such as sore throat, nausea and *malaise*, among those living round the quay at Barking, where there is often an effluvium nuisance, are in some cases, at all events, well founded, and the same may, we believe, be certainly said for similar cases occurring in the neighbourhood of the offensive foreshore at Belfast.

Hill‡ states that the emanations from parts of the tidal Wear, cause ill-health among the inhabitants, many of whom have a particularly unhealthy appearance, and he is also of the opinion that at Durham City the pollution of the river has caused injury to health.

. . . .

The mechanism by which sulphuretted hydrogen is disengaged from putrefying liquids or foul deposits (among which latter certain mud banks may be included) would not appear from the literature relating to sewage and sewage disposal, to have received much special attention although of fundamental importance as regards effluvium nuisances. But in purely scientific literature it will be found that it has formed the subject of numerous investigations and of some controversey.

There can be no question that the gas may be formed directly by the decomposition of albuminoid bodies, and indeed its odour is described as being that of rotten eggs.

It is thus a product of bacterial life and many species of micro-organisms have been enumerated as generating the gas from ordinary culture media. But sulphuretted hydrogen may be produced in a putrefying liquid or in a foul deposit by a totally different mechanism, namely, by the reduction of sulphates.

That such reduction may occur has long been known and its importance in geological metamorphosis was early recognised.

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* Interim Report of Royal Commission on Sewage Disposal, Vol. II. [Cd. 686], 9865–9911.

† A rather singular observation of the late harbour engineer for Belfast may be mentioned in connection with this matter. He informed one of us that he had repeatedly noticed that when the men employed on his dredgers were raising sewage sludge, or what he deemed to be such, they often suffered from a severe form of colic after eating freshly-baked bread, while at other times when eating the same bread they did not do so.

‡ Interim Report of Royal Commission on Sewage Disposal, Vol. II. [Cd. 686], Q. 9031.

Possibly the first to observe it was Bischoff, the following passage occurring in the English translation of his work on chemical and physical geology, bearing the date 1854 :—

"Alkaline and earthy sulphates are reduced by carbonaceous substances in the wet way into sulphurets. This decomposition takes place in mineral waters which contain sulphates, especially sulphate of soda and organic matter. When kept for some time in corked bottles they acquire an odour of sulphuretted hydrogen."

And he also referred the formation of iron pyrites to a similar action. That the formation of sulphuretted hydrogen in mineral waters may be due to biological processes seems to have been first demonstrated by Lothar Meyer* in 1864, who referred the production of the gas to the action of *algœ* in the waters.

Cohn† in 1875 isolated a bacterium from well water which evolved sulphuretted hydrogen, while in 1882 Etard and Olivier‡ proved that in mineral waters sulphate of calcium gives rise to sulphuretted hydrogen or even to free sulphur.

Hoppe Seyler§ in 1886 described the fermentation of cellulose, with and without the addition of sulphates, by the agency of one of the butyric ferments—*B. Amylobacter.*

In the latter case the cellulose was resolved into equal volumes of marsh gas and carbonic anhydride, while in the former the volumetric proportions of the evolved gases were changed to ten of carbonic anhydride for one of marsh gas, this being due to the oxidation of the greater part of the marsh gas at the expense of the sulphate, in accordance with the equation :—

$$CH_4 + CaSO_4 = Ca\,CO_3 + H_2S + H_2O.$$

Closely connected with the reduction of sulphates and evolution of sulphuretted hydrogen by particular putrefactive agencies, is the formation of certain marine deposits, more especially the so-called blue muds.

J. Y. Buchanan¶ in an interesting paper on the genesis of these muds propounded the following theory.

"As the result then of the observations which have been recited I was led to believe that the principal agent in the comminution of the mineral matter found at the bottom of both deep and shallow seas and oceans is the ground fauna of the sea which depends for its subsistence on the organic matter which it can extract from the mud.

"In order to fit them for collecting their nutriment in this way the animals have been fitted with different forms of masticating or milling apparatus, so as to thoroughly deal with the matter which passes through their bodies. It has been shown that most silicates are decomposed to a certain extent when ground or pulverized under water so that mere mastication of the sand or mud in presence of pure water would have a decomposing action on the silicates which it contains. This action is much assisted, in the case of marine animals, by the fact that the water which they pass through their bodies along with the sand is charged with sulphates. These are easily reduced to sulphides by the action of the organic matter of the secretions of the animals.¶¶ The resulting sulphide at once suffers double decomposition with any oxide of iron or manganese which is present as such in the mud, or may be set at liberty from silicates under the decomposing influence of trituration under water. The sulphides of iron and manganese so formed are in course of nature extruded by the animals, and if exposed to the sea water on the surface of the mud are quickly oxidized, the manganese taking priority. The mud below the surface layer in localities where ground life is abundant, remains there, being protected by the oxidation of what is above it.

"At the bottom of the ocean the mineral matter is thus exposed to a reducing process due to the life of the animals which inhabit it, and to an oxidizing process due to the oxygen dissolved in the water. Other things being equal the redness or blueness of a mud or clay depends on the relative activity of these processes."

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* Lothar Meyer, *Journ. f. Prak. Chem.*, Vol. XCI.

† Cohn, *Beiträge zur Biologie der Pflanzen*, Vol. VII., Part III., 1875.

‡ Compt. Rend., 1882.

§ Hoppe Seyler, *Zeitsch. f. Physiol. Chemie*, Vol. X., Part V., 1886.

¶ J. Y. Buchanan, *Proc. Roy. Soc.*, Edinburgh, XVIII., p. 17.

¶¶ Compare the reduction of manganese peroxide by bacteria in presence of sewage solid matters, pp. 32 and 53.

Irvine and Gibson* combat Buchanan's theory of the formation of manganese sulphide as a result of animal life on the ground that sea water containing excess of carbonic anhydride must always be present, while they proved experimentally that when sulphide of manganese is added to sea water in quantity not more than sufficient to form carbonate of manganese with all the carbonic acid present in the sea water, the sulphide is completely decomposed, sulphuretted hydrogen being liberated and the manganese dissolved On the other hand they agree with Buchanan that sulphide of iron is formed under the conditions referred to by him, and they state that unlike sulphide of manganese it is readily formed in the presence of sea water whether mixed with carbonate of lime or not, and that solutions of carbonic acid or of bicarbonates do not decompose it, or prevent its formation.

We shall have occasion later on to show that they are in error as regards the latter part of this statement.

Murray and Irvine†, in an important paper, give an account of their examination of the water intimately associated with the muds, which they obtained by allowing considerable quantities of the dredged mud to drain from a suspended canvas bag.

They found that this water had a different composition from the overlying normal water: the chief points of difference being that the former contained (1) less sulphates, (2) showed a higher alkalinity, and (3) contained much more free and albumenoid ammonia than the latter.

At first they were inclined to refer the great increase of alkalinity observed to the excess of carbonate of lime derived from the solution of the dead shells of calcareous organisms by carbonic acid, the latter being much increased (they say) in sea water through the deoxidation of the sulphates by organic matter, but the total lime present in the water filtered from the mud was found on determination not to have been increased to any notable degree above that present in normal sea-water, and it was also observed that the increase of alkalinity was approximately proportionate to the diminution of the sulphates.

Eventually, however, they came to the conclusion that the principal increase of alkalinity is due to the deoxidation of sulphates by the organic matters in the mud and the subsequent decomposition of alkaline or earthy sulphides by the carbonic anhydride thus produced.

The principal reactions which occur in mud waters they give as follows:—

$$(1)\ RSO_4 + 2C = 2CO_2 + RS$$

where R is an "earthy alkaline" metal.

$$(2)\ RS + 2CO_2 + H_2O = H_2S + RCO_3 + CO_2.$$

$$(3)\ RS + RCO_3 + CO_2 + H_2O = 2\,RCO_3 + H_2S.$$

On the sulphuretted hydrogen meeting with ferric oxide present in the surface layer of these muds the following reaction occurs:—

$$(4)\ Fe_2O_3\ \ 3H_2S = 2FeS + S + 3H_2O.$$

"Part of the sulphur is thus fixed in the mud and part, if there be not sufficient iron in the mud, may escape into the water alone, where meeting oxygen it will be converted into sulphuric acid (H_2SO_4) and return into RSO_4. The products RCO_3, CO_2 in (2) and RCO_3 in (3), or the bicarbonate and carbonate of the metal, are found in the water strained from the mud as above described. . . . The sulphur thus reduced from the sulphates may in part on passing, as hydrosulphuric acid into the water immediately above the mud, become oxidised back again into sulphuric acid, which, in turn, decomposing the carbonate of lime always present in the water (or in the deposit) would re-form sulphates."

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* Irvine and Gibson, *Proc. Roy. Soc. Edinburgh*, Vol. XVIII., p. 54.

† Murray and Irvine, *Trans. Roy. Soc. Edinburgh*, Vol. XXXVII., Part II., p. 481.

W. N. Hartley* somewhat severely criticises these equations on the grounds (1) that they are written without reference to the part played by water in the chemical changes involved and (2) that sulphuretted hydrogen, according to his own experiments on the matter, is not oxidised to sulphuric acid by dissolved oxygen, but from Winogradsky's observation is converted by *beggiatoæ* first into sulphur and later to sulphuric acid by a process which may be termed "respiratory," for the reason that it is a cause of chemical change, liberating energy in the form of heat.

Hartley then draws attention to the large quantities of sulphuretted hydrogen found in the waters of the Black Sea and to Andrussow's paper on the subject, and also to Zelinsky's discovery of the organism *B. Hydrosulphureum* Ponticum, which causes the production of the gas. This organism he says appears to live upon the cellulose of vegetable débris and it abstracts oxygen from sulphates.

He next gives thermochemical data to prove that Hoppe Seyler's theory of sulphate reduction by the fermentation of cellulose is correct, the total heat effect being evolution. Also further data of a similar kind to prove that when sulphuretted hydrogen is oxidized first to solid sulphur and then to dissolved sulphuric acid, more heat is evolved than when it is oxidized to sulphuric acid directly without separation of sulphur. It seems to us that such a conclusion is opposed to Hess' law of the initial and final states.

In view of some of the thermochemical data given, the concluding paragraph of Hartley's paper is difficult to understand. This runs as follows :—

"It may easily be shown by thermochemical equations that neither organic matter nor carbon itself can reduce sulphates such as calcium sulphate to sulphides, except at a high temperature, because the thermal effect results in an absorption of heat under the most favourable conditions for such chemical changes."

Beyerink†, in a series of papers on the cause of the reduction of sulphates by natural processes, first draws attention, in the introduction, to the general importance of the subject: biologically in relation to the occurrence of a somewhat extensive flora and fauna specifically adapted to an existence in (solution of) sulphuretted hydrogen. Geologically on account of the occurrence of extensive deposits rich in ferrous sulphide occurring at the bottom of lakes and even seas. Thus it would appear, he says, that the bed of the Black Sea is coated with an enormous layer of ooze containing that substance, above which the water for a considerable height contains sulphuretted hydrogen—as much as 6·5 cc. per litre having been found at a depth of 2,125 metres.

He next discusses the different modes of formation of "biogenic" sulphuretted hydrogen and as regards the production of the gas itself or of sulphides generally, by micro-organisms, arranges the possible methods of formation as follows :—

(1) Decomposition of proteids containing sulphur.

(2) Directly from free ("regulinischen") sulphur.

(3) From sulphides and hyposulphites, the latter with preliminary resolution into sulphide and sulphur.

(4) The reduction of sulphates.

The last of these he says is probably of chief importance, and Beyerink's experimental investigation deals practically entirely with it.

In this investigation the reduction of sulphates was first traced in "raw" cultures, in which he added, either to sewage alone or to sewage *plus* potassium phosphate and organic substances (such as asparagin and sodium malate or lactate), a definite quantity of a sulphate—for example, magnesium or calcium sulphate. Mixtures of these were placed under such conditions that no air could gain admission, as for instance by completely filling a stoppered bottle with them, and they were then incubated at a gentle heat.

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* W. N. Hartley, *Trans. Roy. Soc. Edinburgh*, Vol. XXI., p. 25.

† W. M. Beyerink, "Ueber Spirillum *Desulphuricans* als Ursache von Sulfat-Reduction," *Centralblatt f. Bakteriologie*, Bd. I. [1895], Abt. 2, pp. 1, 49, and 104.

From time to time the sulphuretted hydrogen produced was determined iodometrically, while the complete disappearance or otherwise of the added sulphate was ascertained by qualitative tests.

Eventually Beyerink succeeded, though with difficulty, in isolating the specific micro-organism concerned and in inducing powerful sulphate reduction by its means in pure cultures. The following is a summary of the chief facts elicited by the investigation.

(1) The reduction of sulphates is caused by a specific organism which is a spirillum about 4μ long and 1μ thick. The number of convolutions (*windungen*) is $\frac{1}{2}$ to 1, more than one convolution being rare. Most individuals are fairly rapidly motile, but only so long as oxygen is excluded. The organism is indeed strictly anærobic, but it does not cause the evolution of hydrogen. It therefore merely reduces sulphates to sulphides, and sulphuretted hydrogen is produced from the latter by an action to be discussed presently. Organisms which, like the butyric ferment, cause evolution of hydrogen, are incapable of reducing sulphates, thus disposing of a theory which has from time to time been advanced to account for the formation of sulphuretted hydrogen during putrefaction.

(2) *Microspira*, or *Spirillum, Desulphuricans* occurs in sewage during July, August and September abundantly, but later in the year in much smaller quantities, or is completely absent. It is invariably present in sewage sludge, and Beyerink also detected it in garden mould.

(3) Sulphate reduction occurs most readily in very dilute nutrient media, and the growth of the organism is inhibited by the presence of acids, hence sugar should either not be present at all, or, if so, in such small quantities that in "raw" cultures the other organisms rapidly oxidize them to water and carbonic anhydride. Phosphates and other saline substances must be present, but only small quantities of nitrogenous substances are necessary—ordinary sewage containing sufficient of these for the reduction of 60mgs. per litre of SO_3. The presence of a small quantity of a ferrous salt indicates the progress of sulphate reduction by the darkening of the liquid.

(4) The most favourable temperature for sulphate reduction lies somewhere about 25°C., though it still takes place to a certain extent at 40°C. Below 20°C. it is uncertain, and often does not occur at all.

. . . .

Some years after the publication of the above investigation, Van Delden* again took up the subject at Beyerink's suggestion, more especially with regard to the very strong sulphuretted hydrogen evolution occurring round the Dutch coasts; and particularly in the estuaries ("Wadden") where the seabed is black for several metres below the surface—which latter is oxidized and brown to a depth of a few millimetres or centimetres only.

His first experiments were, however, conducted with fresh water, and were to a considerable extent a repetition of those performed by Beyerink.

Thus he found that all the sulphates in (Delft ?) sewage (44·8 mgs. SO_3 per litre) were reduced without the addition of anything except 0·2 grms. per litre of potassium phosphate when incubated at 28°C. for a week, and that the equivalent quantity of sulphuretted hydrogen (19 mgs. per litre) was evolved.

In other experiments conducted with artificial solutions, he obtained a more extensive sulphate reduction than Beyerink. Thus with the following :—

Tap water	1,000
Potassium phosphate	0·5
Asparagin	1·0
Sodium lactate	5·0
Gypsum	1·0

inoculated with sewage sludge and incubated (in a completely filled stoppered bottle) at 28°C., the whole of the sulphate (580 mgs. SO_3) disappeared in forty-one days with equivalent evolution of sulphuretted hydrogen (246 mgs. per litre), thus showing that *Microspira desulphuricans* can exist in high concentration of that gas.

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* A. van Delden, "Beitrag zur Kenntniss der Sulfat-reduction durch Bakterien," *Centralblatt fur Bakteriologie*, etc., Bd. XI. (1903) Abt. 2, pp. 81 and 113.

He also proved experimentally that a certain quantity of organic matter is necessary for sulphate reduction, the action ceasing after a time when much sulphate is present with only a little organic matter, but is rapidly renewed on adding more of the latter.

Van Delden next describes an improved method for isolating *M. desulphuricans*, depending mainly upon the addition of sulphuretted hydrogen to the gelatine culture medium. Incidentally he isolated another organism which both microscopically and in the appearance of its colonies resembles *M. desulphuricans*, but which, however, does not possess the power of reducing sulphates. On the other hand, it can reduce both sulphites and hyposulphites with evolution of sulphuretted hydrogen, and also in presence of small quantities of oxygen causes the separation of sulphur from the latter. But this organism is not aerobic, and is not, therefore, Zelinsky's *B. hydrosulphureum ponticum.*

Experimenting next with pure cultures of *M. desulphuricans*, he found that it would grow in concentrated solutions of organic substances, while in "raw" cultures, such concentration leads to its suppression by putrefactive organisms. The pure cultures have powerful reducing properties, and with them he obtained a concentration of sulphuretted hydrogen up to 238 mgs. per litre (in eighteen days).

Van Delden next turned his attention to the reduction of sulphates in sea water, and commenced the investigation with "raw" cultures, in which he used similar solutions to those employed in the fresh water experiments, with the difference, however, of either substituting sea water for fresh water, or of adding 3 per cent. of salt to the latter. These were inoculated as a rule with a little black (sea) sludge taken near the exit of a drain into the Dollard, and after incubation were found to contain extraordinary quantities of sulphuretted hydrogen.

Thus in one experiment in which the following solution was employed :—

Tap water - - - - - - - -	1,000
Common salt - - - - - - - -	30
Sodium lactate - - - - - - -	10
Crystallized magnesium sulphate - - - - -	8
Potassium phosphate - - - - - -	0·5
Asparagin - - - - - - - - -	0·5

no less than 1,030 mgs. per litre of sulphuretted hydrogen were produced and the whole of the sulphate disappeared. The latter, calculated as SO_3, amounted originally to 2,424 mgs. per litre, an amount exceeding the average quantity found in sea water, which Van Delden gives as being 2,100–2,200 mgs. per litre. In experiments with mixtures of sea water, potassium phosphate, asparagin and sodium lactate—but without added sulphate, 1,984 mgs. SO_3 per litre found originally, disappeared, and 843 mgs. of sulphuretted hydrogen were produced.

Van Delden had no difficulty in isolating the organism causing the reduction of sulphates in sea water, which he found to closely resemble *M. desulphuricans.* He named it *M. estuarii.*

Experimenting with pure cultures he found it to possess very energetic sulphate reducing powers, obtaining as much as 952 mgs. of sulphuretted hydrogen per litre. Like *M. desulphuricans* it thrives when in pure culture in high concentration of organic matter. The fresh water and sea water organisms were next studied in relation to the question of salinity, and the results may be summarised thus :—

Percentage of Salt in the Culture Fluid		0	½	1	1½	2	2½	3
Mgs. per litre of SO_3 reduced by	M. Desulfuricans	532	500	528	532	320	80	0
	M. Estuarii	0	240	1,000	1,200	1,140	1,108	1,280

From which it appears probable that the two are distinct species, though possibly they are not so, but are modifications of the same species, which have become gradually acclimatised to fresh and salt water respectively.

It is evident, however, that both can thrive in brackish water.

Van Delden concludes his two papers on sulphate reduction by a discussion of the chemical changes leading eventually to the evolution of sulphuretted hydrogen. Recalling the fact that sulphate reduction can only occur in presence of organic matter—the reason he says, is, that the combustion of this organic matter supplies the energy necessary for the reduction, and consequently there should be a definite relationship between the amount of carbonic anhydride and sulphuretted hydrogen evolved—the former deriving its oxygen from the sulphate reduced, and consequently its amount should be also proportional to that of the sulphate disappearing.

Further, in a culture fluid containing no other organic matter than sodium lactate, the eventual chemical change must be somewhat in accordance with the equation :—

$$2\ C_3H_5O_3\ Na + 3\ Mg.\ SO_4 = 3\ Mg.\ CO_3 + Na_2\ CO_3 + 2\ CO_2 + 2\ H_2O + 3\ H_2S.$$

In which for every molecule of sulphuretted hydrogen formed, two of carbonic anhydride are produced, either free or combined.

To test this theory he conducted experiments on the reduction of magnesium sulphate in a solution containing in addition, sodium lactate, common salt, phosphate of potassium, and ammonium chloride (as nitrogenous nourishment): the mixture being inoculated with *M. Estuarii*, and placed in completely filled stoppered bottles. Eventually (after eighteen days incubation at 28°C.) separate determinations were made of the total carbonic anhydride and sulphuretted hydrogen, when (after subtracting the carbonic anhydride originally present in the liquid) quantities of the two were found agreeing fairly well with those required for the above equation.

Experiments conducted on similar lines with *M. desulphuricans* led to a similar result, and when potassium lactate was substituted for the sodium salt the ratio remained unchanged.

Van Delden compares sulphate reduction with denitrification, the combined oxygen in both cases playing a similar role in the oxidation of organic matter, and assisting in the natural processes of the self-purification of foul waters.

* * * * * *

While Beyerink and Van Delden's researches give a complete and probably the correct explanation of sulphate reduction in both fresh and sea water, and also no doubt indicate that the bulk of the sulphuretted hydrogen occurring both in foul sewage and from certain mud banks, owes its origin rather to sulphates than to albuminoid bodies, they leave one aspect of the question, and an important one, untouched experimentally, namely the rôle played by ferrous sulphide, which, as is generally acknowledged, appears to be the sulphide chiefly *en evidence* in foul deposits.

How is this substance formed ? and when formed, is sulphuretted hydrogen evolved from it by natural processes—and, if so, by what chemical mechanism ? In order if possible to answer this and certain other questions connected with foul deposits occurring in both fresh and sea water, Mr. J. L. McKee, B.A., and 1851 Exhibition Scholar, has at the suggestion of one of us made an investigation, of which the following account may be given :—

"(1) REPETITION OF BEYERINK AND VAN DELDEN'S EXPERIMENTS.

The following experiments with "raw" cultures were made. In each case a bottle of about one litre capacity, and completely filled with the solution (which previous to use had been boiled to get rid of dissolved oxygen), was employed.

The liquid was then inoculated with a trace of foul mud, or a small portion of the liquid from another culture, and finally the bottle was stoppered and placed in an incubator at 80° F. (= 27° C.). The sulphide was determined by running 10 c.c. of the culture fluid into excess of a dilute standard solution of iodine (1 cc. = 0·2 mgm. H_2S) and titrating back with sodium thiosulphate of equivalent strength.

In each experiment a small bottle was filled with the inoculated culture fluid and a small quantity of ferrous sulphate, to indicate the progress of the reduction by the formation of ferrous sulphide and consequent blackening of the fluid.

No. 1.—*Culture Fluid.*

Distilled Water	1000 parts
Na_2SO_4 crystallised	0·7 ,,
Amm. Tartrate	0·5 ,,
K_2HPO_4	0·5 ,,
Glucose	0·05 ,,

For inoculation a small trace of foul mud (Sample 2) was used.

Mgms. H_2S per litre found at the end of the { 15th day = 62·6
24th ,, = 60·0

It will be seen that no sodium chloride was present in the above solution. In all the subsequent experiments either that salt was added in about the proportion found in sea water, or sea water itself was used.

The mud employed for inoculation was from a tidal timber pond into which, however, fresh water was discharged. Van Delden has shown that *M. Estuarii* perishes in fresh water, from which it would appear that the organism active in the above experiments was *M. Desulphuricans.* On the other hand, the inoculation also succeeded in sea water, in which *M. Desulphuricans* perishes. Thus both organisms appear to have been present in the mud, which is not surprising, as both can thrive in brackish water.

No. 2.—*Culture Fluid.*

Tap Water	1000 parts
Asparagin	1 ,,
K_2HPO_4	0·5 ,,
$MgSO_4$ crystallised	8 ,,
NaCl	30 ,,

The inoculation was made with a trace of foul mud (Sample 1) from Belfast Lough.

Mgms. H_2S per litre found at the end of the { 12th day = 245·5
21st ,, = 321·4
49th ,, = 207·0

at the end of the 49th day much sulphate was still present.

From the large quantity of sulphuretted hydrogen produced in this experiment, and also from the salinity of the solution, it would appear probable that the active organism present was *M. Estuarii.* It will be seen that at the end of the 49th day there was only about two-thirds of the quantity of sulphuretted hydrogen found at the end of the 21st day, the loss being possibly due to organisms which are able to decompose this gas into sulphur and hydrogen.

No. 3.—*Culture Fluid.*

Tap Water	1000 parts
Asparagin	1 ,,
K_2HPO_4	0·5 ,,
Na_2SO_4 crystallised	10·5 ,,
NaCl	30 ,,

The inoculation was performed with a trace of foul mud (Sample 1).

Mgms. of H_2S per litre found at the end of the } 12th day = 103.

All the sulphate had disappeared when the above estimation was made.

The small amount of sulphuretted hydrogen appearing while all the sulphate had disappeared is rather striking; but I am unable at present to give any theory to account for it.

No. 4.—*Culture Fluid.*

Sea Water	1000 parts
Asparagin	1·0 ,,
K_2HPO_4	0·5 ,,

The solution was inoculated with a small portion of the liquid from No. 2, after the latter had become active.

Mgms. per litre found at the end of the { 13th day = 292.
19th ,, = 303.

(*Much Sulphate still present.*)

At the time when the last of these determinations was made, the alkalinity was also determined in the following manner:—

(A.)—*Alkaline Carbonates.*

25 cc. of the solution were boiled till about half had vaporised, the solution filtered from the precipitated carbonates, and the filtrate titrated with $\frac{N}{10}$ H.Cl.

Amount of this required	1·1 cc.
25 cc. sea water treated in the same way, required	0·14 cc.
Difference =	·96 cc.

∴ 1000 cc. contain ·96 × 40 × 2·2 = 84·5 mgs. CO_2 in combination with alkali metals.

(B.)—*Alkaline Earth Carbonates.*

25 cc. of the solution were evaporated to dryness, and the residue titrated with $\frac{N}{10}$ H.Cl.

Amount of this required	1·75 cc.
25 cc. sea water similarly treated, required	0·60 cc.
	1·15 cc.

∴ 1000 cc. contain 1·15 × 40 × 2·2 = 101·2 mgs. CO_2 in combination.

Deducting amount found for alkaline carbonates = 16·7 mgs. CO_2 in combination with alkaline earth metals.

It will be seen from the above results that at least $\frac{5}{6}$ of the carbonates formed are combined with alkali metals, and it is therefore probable that the sulphates of potassium and sodium are more readily attacked by *M. Estuarii* than the sulphates of calcium and magnesium, which, according to Dittmar,* occur in larger quantities in sea water.

(2) THE ACTION OF CARBONIC ACID ON FERROUS SULPHIDE.

A preliminary experiment showed that when carbonic anhydride was passed through recently precipitated and washed ferrous sulphide suspended in water, the escaping gas blackened lead paper.†

An experiment was next made to ascertain the amount of sulphuretted hydrogen which might thus be produced.

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* Dittmar (Challenger Report) gives as the approximate amount of the various sulphates present in 100 parts of the solids in sea water:—

Potassium sulphate	2·465
Magnesium ,,	4·323
Calcium ,,	4·070

† A similar observation had been made previously by Professor Letts though the method of experiment was different.

For this purpose an apparatus was constructed consisting of a carbonic anhydride generator (Kipp) connected with a wash bottle containing water and a second one containing a mixture of carbonate of soda and ferrous sulphate (to remove possible traces of oxygen) and finally with a flask provided with a cork and two tubes which contained water and ferrous sulphide. The purified carbonic anhydride bubbled into this flask through a tube passing nearly to its bottom, and could either be allowed to escape through a shorter tube or this latter could be plugged.

The method employed was as follows :—

All the various parts of the apparatus were first filled with CO_2. The ferrous sulphide was then prepared and transferred to the flask made ready for it by means of a litre of air-free water which had been saturated with CO_2. A rapid current of CO_2 was then passed through the contents of the flask for about 10 minutes, and finally the shorter tube was plugged. On account of the rapidity with which the ferrous sulphide is oxidised by contact with the air no attempt was made to weigh it, but the quantity precipitated from excess of ferrous sulphate solution by 10 cc. of a particular solution of colourless ammonium sulphide (freshly prepared) was rapidly washed and transferred to the flask with as little loss as possible, the amount transferred being determined volumetrically afterwards (*see* below.) The flask had a capacity of about 1½ litres, so that there was about ½ litre of CO_2 above the liquid. As the CO_2 was absorbed the pressure above the liquid decreased and more gas bubbled in, keeping the solution saturated. The sulphide flasks were kept in an incubator at 35°C., the rubber tubing connecting them to the gas generator passing through a small hole in the top. The apparatus was left undisturbed until all absorption of the CO_2 had ceased, which required about eight days. The sulphide flasks were then disconnected and the free H_2S and undecomposed $Fe\ S$ determined in the following manner.

10 cc. of the clear supernatant liquid were run into excess of standard iodine solution (1 cc. = ·2 mgm. H_2S) and titrated back with sodium thiosulphate of the same strength. Next the flask was well shaken in order to distribute the $Fe\ S$ evenly throughout the liquid, and, still shaking, 10 cc. were withdrawn and run into excess of strongly acidified (with $H\ Cl$) iodine solution, the excess being determined as before.

The first determination gave the amount of H_2S set free, the second the H_2S equivalent of the $Fe\ S$ originally present.

No. (1)—$Fe\ S$ + distilled water :—

H_2S originally present (as $Fe\ S$) = 175 mgm.
H_2S evolved (free) = 16 „

No. (2)—$Fe\ S$ + sea water :—

H_2S originally present (as $Fe\ S$) = 178·5 mgm.
H_2S evolved (free) = 11·5 „

The above figures show that quite enough sulphuretted hydrogen can be obtained from the action of CO_2 on $Fe\ S$ to cause a serious nuisance. Probably the reaction is a reversible one, namely :—

$$Fe\ S + 2\ CO_2 + 2\ H_2O \rightleftarrows Fe\ (H\ CO_3)_2 + H_2S$$

The ferrous sulphide used was liable to contain traces of its oxidation products, but these would only reduce the amount of H_2S evolved.

The decomposition of the ferrous sulphide in oceanic deposits by CO_2 has been frequently denied, but in the light of the above experiments there cannot be any doubt that this reaction takes place ; though probably much less readily than the decomposition of the sulphides of the alkali and alkaline earth metals by CO_2.

(3) EVOLUTION OF SULPHURETTED HYDROGEN FROM FOUL MUD* KEPT IN CONTACT WITH A SATURATED SOLUTION OF CARBONIC ACID.

While the above experiments with FeS were being conducted, another flask, containing 100 grms. wet mud and 1 litre distilled water was also treated with carbonic anhydride in the same manner. The mud was part of a sample collected from Belfast Lough close to the pumping station of the sewage works (Sample No. 1). The free H_2S at the end of the experiment was determined as before, but the total sulphide was obtained by strongly acidifying the liquid containing the mud, allowing it to stand overnight in a stoppered bottle containing no oxygen (the space above the liquid being filled with CO_2) in the incubator and then determining the H_2S in the usual way.

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* For the composition of the mud employed, see pp. 130–131.

100 grms. wet mud = 60·4 grms. dry mud and 1,000 cc. distilled water.
H_2S originally present (as FeS, etc.) = 83·6 mgms.
H_2S evolved - - - - - = 66·0 „

There is a remarkable difference in the amount of the sulphide decomposed in this experiment and in those where pure Fe S was used. Perhaps some of the H_2S evolved here was due to other causes, such as bacterial action, or the presence of other sulphides, such as Ca S or Mg S—which seems more probable.

* * * * * *

In order to ascertain to what extent Fe S is decomposed by dilute fatty acids, the following experiment was at Professor Letts' suggestion performed by me.

An aqueous solution of normal butyric acid containing 2 grams per litre was mixed with an excess of recently precipitated and washed Fe S. Two bottles were then completely filled with the mixture and stoppered. Portions of the clear liquid were eventually pipetted off and the sulphuretted hydrogen which they contained determined.

The following results were obtained :—

(1) after 36 hours - - - - - - - 27 mgs. H_2S per litre.
(2) after 72 „ - - - - - - - 42 „ „

An experiment was also performed as under with the fermenting *Ulva* :—

(4) Sulphuretted Hydrogen Production from Putrefying Green Seaweeds.

Professor Letts and Mr. John Hawthorne have shown* that when *Ulva latissima* ferments in sea water, two distinct but consecutive changes occur. In the first of these $CO_2 + H_2 +$ fatty acids are formed, while later the residue of the seaweed blackens and H_2S is evolved. Before reading Beyerink and Van Delden's papers the view was expressed that this H_2S might owe its origin to the action of the fatty acids on the Fe S subsequently formed.

A 6-oz. flask was filled with the seaweed and sea water, placed in an incubator at 80°F., and the seaweed allowed to ferment until it was judged that no more hydrogen came off, but no H_2S was detected and the liquid was strongly acid. This liquid was poured off and kept in a small flask nearly filled with it in the incubator. It soon blackened and gave off abundance of H_2S. After some time its reaction was found to be *alkaline*. On evaporating the filtered liquid to dryness and adding strong sulphuric acid to the residue the *odour of butyric acid was apparent.*

After pouring off the above liquid from the partially decayed seaweed, the flask containing the latter was again filled with sea water which soon became strongly acid. After some weeks sulphuretted hydrogen began to be evolved and the liquid *was still acid.*

The results of this experiment appear to indicate that the view expressed originally by Professor Letts and Mr. Hawthorne is at least in part correct, viz., that fatty acids are first produced by the decomposition of the seaweed, while later and by a distinct fermentative action (no doubt induced by *M. Estuarii*) ferrous sulphide is produced which is then partly decomposed by the fatty acids. The gradual neutralisation of the latter with the subsequent appearance of alkalinity in the solution can be explained if it is assumed that the potassium or sodium sulphate present in the seaweed or sea water is reduced to sulphide and eventually to carbonate and sulphuretted hydrogen by the carbonic anhydride generated in the fermentation. Thus while the fatty acids cause the evolution of some sulphuretted hydrogen, carbonic anhydride probably also contributes to its formation."

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* *Proc. Roy. Soc. Edinburgh*, XXIII., pp. 268–295.

* * * * * *

The foregoing experiments, while incomplete, at least prove that ferrous sulphide is decomposed by carbonic anhydride in presence of water.

The following scheme may be tentatively suggested as probably indicating the principal changes occurring :

$$(1)\ \text{Sea water} \left\{\begin{matrix} M'_2SO_4 \\ M''SO_4 \end{matrix}\right. + \begin{matrix}\text{Organic matter and} \\ \textit{M. Estuarii}\end{matrix} = \left\{\begin{matrix} M'_2S \\ M''S \end{matrix}\right. + CO_2 + H_2O + NH_3$$

$$(2)\ \left\{\begin{matrix} M'_2S \\ M''S \end{matrix}\right. + 2CO_2 + 2H_2O = \left\{\begin{matrix} 2M'HCO_3 \\ M''(HCO_3)_2 \end{matrix}\right. + H_2S$$

$$(3)\ \begin{matrix}\text{Sea bed} \\ \text{or silt}\end{matrix}\left\}\begin{matrix} Fe_2O_3 \\ Fe_2(OH)_6 \end{matrix}\right. + \begin{matrix}\text{Fermenting organic matter} \\ (=\text{reducing agent})\end{matrix} = \left\{\begin{matrix} 2FeO \\ 2Fe(OH)_2 \end{matrix}\right. + H_2O$$

$$(4)\ H_2S + \left\{\begin{matrix} FeO \\ Fe(OH)_2 \end{matrix}\right. = \left\{\begin{matrix} FeS + H_2O \\ FeS + 2H_2O \end{matrix}\right.$$

$$(5)\ FeS + 2CO_2 + 2H_2O \rightleftarrows Fe(HCO_3)_2 + H_2S$$

where M′ is a metal of the alkalies and M″ an alkaline earth metal.

The reduction of ferric oxide or hydrate is usually represented as being caused by the sulphuretted hydrogen, with separation of sulphur, but in a strictly anærobic fermentation such as that induced by *M. Estuarii* it seems probable that any ferric compounds would be reduced to the corresponding ferrous compounds before the sulphates would be attacked."

* * * * * *

[In relation both to the above experiments and observations of Mr. McKee, and to the question of sulphate reduction by micro-organisms also, it is of interest to investigate the matter from the thermo-chemical side, and for this purpose the following data may first be given.

Thermochemical Data.

Heat of formation of :—

(1) Dissolved Potassium Sulphate.

$K_2, O, H_2O = 165{\cdot}2$ Cal.
$S, O_3, H_2O = 141{\cdot}1$ „
$2KHO, H_2SO_4 = 31{\cdot}4$ „
$337{\cdot}7$ „

Dissolved Potassium Sulphide.

$K_2, S = 113{\cdot}5$ Cal.

∴ Heat of formation of K_2S from K_2SO_4
$113{\cdot}5 - 337{\cdot}7 = -224{\cdot}2$ Cal.

(2) Dissolved Sodium Sulphate.

$Na_2, O, H_2O = 155{\cdot}9$ Cal.
$S, O_3, H_2O = 141{\cdot}1$ „
$2NaHO, H_2SO_4 = 31{\cdot}7$ „
$328{\cdot}7$ „

Dissolved Sodium Sulphide

$Na_2, S = 104{\cdot}3$ Cal.

∴ Heat of formation of Na_2S from Na_2SO_4
$104{\cdot}3 - 328{\cdot}7 = -224{\cdot}4$ Cal.

(3) Dissolved Calcium Sulphate.

$$\begin{aligned} Ca, O, H_2O &= 149{\cdot}6 \text{ Cal.} \\ S, O_4, H_2O &= 141{\cdot}1 \text{ ,,} \\ Ca(OH)_2, H_2SO_4 &= 31{\cdot}2 \text{ ,,} \\ & \overline{321{\cdot}9} \text{ ,,} \end{aligned}$$

Dissolved Calcium Sulphide.

$Ca, S, (Aq) = 97{\cdot}1$ Cal.

Solid Calcium Sulphide.

$Ca, S = 90{\cdot}8$ Cal.

∴ Heat of formation of CaS (solution) from $CaSO_4$ (solution)

$$97{\cdot}1 - 321{\cdot}9 = -224{\cdot}8 \text{ Cal.}$$

and Heat of formation of CaS (solid) from $CaSO_4$ (solution)

$$90{\cdot}8 - 321{\cdot}9 = -231{\cdot}1 \text{ Cal.}$$

(4) Dissolved Magnesium Sulphate.

$$\begin{aligned} Mg, O, H_2O &= 148{\cdot}8 \text{ Cal.} \\ S, O_4, H_2O &= 141{\cdot}1 \text{ ,,} \\ Mg(OH)_2, H_2SO_4 &= 31{\cdot}2 \text{ ,,} \\ & \overline{321{\cdot}1} \text{ ,,} \end{aligned}$$

Solid Magnesium Sulphide.

$Mg, S = 79{\cdot}4$ Cal.

∴ Heat of formation of MgS (solid) from $MgSO_4$ (solution)

$$79{\cdot}4 - 321{\cdot}1 = -241{\cdot}7 \text{ Cal.}$$

Heat of combustion of asparagine = 448 Cal.

Heat of formation of ammonia (dissolved) = 21 Cal.

From the above data it is seen that the amount of energy which must be expended in the reduction of the sulphates of the four metals increases from potassium to magnesium, and hence it would seem probable that in a mixture of the four sulphates the potassium or sodium compounds would be reduced first and the calcium and magnesium compounds last.

This would account for the considerable alkalinity noticed in all the (polluted sea) mud samples we examined qualitatively, and also for the alkaline carbonate produced in Mr. McKee's experiment No. 4, p. 124.

Regarding the thermochemical relationships in sulphate reduction by micro-organisms, it may be assumed that in this experiment of Mr. McKee's (where the only organic nourishment supplied was asparagine) the reaction in all probability occurred in the following manner:—

$$2(C_4H_8N_2O_3)+3\left\{\begin{matrix}R_2SO_4\\R''SO_4\end{matrix}\right.=4NH_3+2H_2O+8CO_2+3\left\{\begin{matrix}R_2S\\R''S\end{matrix}\right.$$

which from the thermochemical standpoint may be treated thus :—

Heat of combustion of 2 gram molecules of asparagine, less heat of formation of 4 gram molecules of ammonia gives the available energy for the sulphate reduction, that is to say :

$$(2 \times 448) - (4 \times 21) = 812 \text{ Cal.}$$

Heat required for the reduction of 3 gram molecules of sulphate into sulphide :—

Potassium sulphate	$3 \times 224{\cdot}2 = 672{\cdot}6$ Cal.
Sodium ,,	$3 \times 224{\cdot}4 = 673{\cdot}2$,,
Calcium ,,	$3 \times 224{\cdot}8 = 674{\cdot}4$,,
Magnesium ,,	$3 \times 241{\cdot}7 = 725{\cdot}1$,,

which leaves a considerable balance of heat evolution—no matter which sulphate is reduced. We are therefore unable to agree with Professor Hartley in the statement already quoted on p. 119].

APPENDIX TO DIRECT NUISANCES.

ON CERTAIN PROPERTIES OF FOUL MUD.

During our tour of inspection of some of the chief estuaries in England, we were much struck with the extraordinary amount of mud in suspension in the tidal reaches of certain rivers, and more especially in those of the Thames, Usk and Humber.

It seemed to us that the intimate commingling of the river water with its bed, caused by a rapid current on the one hand, and finely divided particles on the other, must lead to fairly rapid chemical changes in the water—supposing the mud or silt forming the river's bed to be polluted.

This suggestion led us to the consideration of the following questions, which, however, we have only been able to submit to but slight experimental investigation. The results, however, appear to us to be of sufficient interest to warrant their publication.

The preliminary experiments were entrusted to Mr. James L. McKee, and the following is an account of his work.

1.—Locality and Analysis of the Deposits.*

"Sample 1 was collected at the Antrim side of Belfast Lough about 100 yards from the shore and close to the pumping station.

Sample 2 was collected in the Timber Pond near Duncrue Street, Belfast, at the north end, near the outlet into the outer timber pond, into which the storm overflow of the main sewer discharges.

Sample 1 was black and slimy in appearance and had a strong odour of sulphuretted hydrogen. A surface exposed to the air quickly turned grey from oxidation. The sample contained a large number of small worms which apparently required oxygen as they contained red blood. For the oxygen they would have to come to the surface, or to the water at some distance from the mud, as the latter quickly absorbs oxygen.

The mud was stored in wide mouthed stoppered bottles which were originally quite full. After it had remained in these for a few days the worms came to the top and they were taken out and thrown away. Before removing a portion of the mud for analysis the upper layer (which was liable to oxidation) was discarded, and when a bottle had been opened once or twice its use was discontinued.

The total amount of nitrogen was determined by Kjeldahl's method. A portion of the mud was transferred to a porcelain dish and dried in an air oven at 110°C. It was then gently powdered by means of a pestle, care being taken not to crush any small stones present, and was sifted through a piece of wire gauge. About 1 grm. of the sifted mud was weighed into a hard glass flask and $\frac{1}{2}$ grm. crystals of potassium sulphate and 4 c.c. con. sulphuric acid were added. The flask was then heated over a ring burner for four hours, cooled, and the contents, now colourless, rinsed into a distilling flask by means of 200 c.c. ammonia free water. The solution was rendered alkaline by a measured volume of caustic potash solution, and 100 c.c. distilled over.

The distillate was then nesslerized in the usual way. A blank experiment was performed using the same quantities of the various reagents.

Total nitrogen thus found = 447 parts per 100,000, or 0·447 per cent.

A portion of the dried and sifted mud was ignited in a porcelain crucible over a small Bunsen flame for six hours. Then moistened with ammonium carbonate (to reconvert any oxide of calcium produced into carbonate), the moisture carefully driven off in an air bath, and the crucible reheated to redness for a few minutes.

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* The deposits are those referred to in Mr. McKee's experiments described in the preceding pages.

There was a negligible gain after this latter treatment.

Mud taken - - - 1·8862 grms.
Loss in weight - ·2325 „
or 12·32 per cent.

The moist mud gave an alkaline reaction with litmus. As this result was rather unexpected* and also of some importance in the problem of the causes of the sulphuretted hydrogen evolution, a number of foul mud samples from various parts of Dublin Bay and Belfast Lough were also tested.

In every case the reaction with litmus was found to be alkaline.

In order to discover the source of the alkalinity a quantity of mud (Sample 1) was extracted with water. The extract was evaporated to dryness, the residue boiled with distilled water and filtered. The filtrate was again evaporated to dryness and the residue was then found to have an alkaline reaction and to effervesce with hydrochloric acid. The mud therefore contained an alkaline carbonate.

Next 100 grms. of the wet mud were taken, about 250 cc. distilled water added and the mixture, after being thoroughly stirred, was transferred to a large filter and allowed to drain for some time.

The residue was washed once or twice and the filtrate and washings evaporated to dryness. This residue now obtained was again treated with boiling water and filtered. The filtrate was titrated with $\frac{N}{10}$ hydrochloric acid.

It required 2·2 cc.

Corresponding to $2{\cdot}2 \times {\cdot}0022 = 0{\cdot}0048$ grms. CO_2.

The mud contained 39·6 per cent. moisture and therefore the dry mud contained

$$\frac{{\cdot}0048 \times 100}{60{\cdot}4} = 0{\cdot}008 \text{ per cent. } CO_2 \text{ in combination with alkaline oxides.}$$

Summary of Results. (Mud Sample 1—dry.)

Total nitrogen - - - - - - - - -	0·447 per cent.
Loss on ignition - - - - - - -	12·32 „
CO_2 as alkali carbonates - - - - - -	0·008 „

Sample 2 was very similar in appearance to Sample 1, but smelled slightly of paraffin oil.

The total nitrogen was determined in the same manner as before and was found to amount to 0·988 per cent.

The loss on ignition was 21·54 per cent.

The moist mud was alkaline to litmus.

The amount of sulphide in this sample was ascertained in the following way. 3 grams. of the wet mud were washed into a 100 c.c. flask (previously filled with carbon dioxide) with air free water. 5 c.c. concentrated hydrochloric acid were added and the flask filled up to the mark. After shaking, the mixture was allowed to settle and 25 c.c. were pipetted out and run into excess of iodine solution. The excess of iodine was then titrated by means of a sodium thiosulphate solution of equivalent strength. (1 c.c. = 0·2 mgs. H_2S).

25 c.c. required $5 - 2{\cdot}38 = 2{\cdot}62$ c.c. of the iodine solution = 0·524 mgs. H_2S.

∴ 3 grms. of the wet mud = $0{\cdot}524 \times 4 = 2{\cdot}096$ „ „

The mud was found to contain 25 per cent. of moisture

∴ 2·25 grms. dry mud = 2·096 mgs. H_2S

and 100 „ „ „ $= \frac{2{\cdot}096 \times 100}{2{\cdot}25} = 93{\cdot}1$ mgs. H_2S.

Assuming that all the sulphide in the mud was present as ferrous sulphide, the sample contained 0·25 per cent. of the latter compound.

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* At the time when the experiment was made which was antecedent to Mr. McKee's work recorded a few pages back.

Summary of Results. (Mud Sample 2—dry.)

Loss on ignition	21·54 per cent.
Total nitrogen	0·99 „
Ferrous sulphide, about	0·25 „

2.—Loss of Dissolved Oxygen from Water in Contact with the above-mentioned Mud Samples.

Method.—About 2 litres of tap water were shaken in a Winchester quart bottle with repeatedly renewed air for ten minutes. The bottle to be used in the experiment was then partly filled with the aerated water, the remainder being poured into a wash bottle, and both bottles placed in an incubator at 80°F. for twenty-four hours. At the end of this time 20 grms. wet mud were weighed into a porcelain dish, the large bottle was taken out of the incubator, and the mud was quickly washed into it by means of the water in the wash bottle and filled to the brim. It was then tightly stoppered, well shaken, and returned to the incubator. The barometer was now read, and the water was assumed to be saturated with air at the temperature of the incubator and at atmospheric pressure. At the end of the period of incubation the dissolved oxygen remaining in the water was determined by the method given by Dr. Letts and Mr. Blake (Scientific Proceedings of the Royal Dublin Society, Vol. IX., part IV., No. 33, 1901).

Temperature of incubator 80° F. = 26·66 C.
Barometer = 76·55 cms.

At 26·66°C. and 76·55 cms. distilled water saturated with air contains 5·85 c.c. dissolved oxygen per litre.

Experiment 1. Period 3 hours. Mud Sample 1.

Dissolved oxygen originally present in the volume of water taken (1660 c.c.)	9·71 c.c.	= 5·85 c.c. per litre.
Ditto found after contact with the mud	5·58 „	= 3·36 „ „ „
Dissolved oxygen disappearing	4·13 c.c.	= 2·49 c.c. „ „

Experiment 2. Period 6½ hours. Mud Sample 1.

Dissolved oxygen originally present in the volume of water taken (1720 c.c.)	10·06 c.c.	= 5·85 c.c. per litre.
Ditto found after contact with the mud	3·87 „	= 2·25 „ „ „
Dissolved oxygen disappearing	6·19 c.c.	= 3·60 c.c. „ „

Experiment 3. Period 10 hours. Mud Sample 1.

Dissolved oxygen originally present in the volume of water taken (1720 c.c.)	10·06 c.c.	= 5·85 c.c. per litre.
Ditto found after contact with the mud	1·14 „	= ·66 „ „ „
Dissolved oxygen disappearing	8·92 c.c.	= 5·19 c.c. „ „

Percentage of the oxygen originally present which was absorbed:—

In 3 hours	In 6½ hours	In 10 hours
42·5	61·5	88·7

The mud contained 49·8 per cent. moisture, therefore in each bottle there was a quantity containing 9·97 grms. dry mud.

Determinations for shorter periods than three hours are extremely difficult, owing to the large amount of suspended matter which does not settle readily.

Experiment 4. Period 3 hours. Mud sample 2

Dissolved oxygen originally present in the volume of water taken (1660 c.c.)	9·71 c.c.	= 5·85 c.c. per litre.
Ditto found after contact with the mud	2·16 „	= 1·30 „ „ „
Dissolved oxygen disappearing	7·55 c.c.	= 4·55 c.c. „ „

Experiment 5.—Period 6½ hours. Mud Sample 2.

Dissolved oxygen originally present in the volume of water taken (1660 c.c.)	9·71 c.c. =	5·85 c.c. per litre.
Ditto found after contact with the mud	·50 ,, =	·30 ,, ,, ,,
Dissolved oxygen disappearing	9·21 c.c. =	5·55 c.c. ,, ,,

Experiment 6. Period = 10 hours Mud Sample 2.

Dissolved oxygen originally present in the volume of water taken (1720 c.c.)	10·06 c.c. =	5·85 c.c. per litre.
Ditto found after contact with the mud	·17 ,, =	·10 ,, ,, ,,
Dissolved oxygen disappearing	9·89 c.c. =	5·75 c.c. ,, ,,

Percentage of the oxygen originally present which was absorbed :—

In 3 hours	In 6½ hours	In 10 hours
77·7	94·9	98·3

The mud contained 64 per cent. moisture, therefore in each bottle there was a quantity containing 7·2 grms. dry mud.

The following experiment shows the relatively very large amount of oxygen these deposits can absorb.

1 grm. wet mud from sample 2, containing ¼ grm. dry mud, was left in contact with 991 c.c. aerated water at 80° F. for fourteen days. At the end of that period all the oxygen originally present in the water, = 5·7 c.c., had disappeared."

* * * * * *

[The following experiments were made by one of us with samples of Thames muds which were kindly collected for the purpose by Dr. W. W. Willoughby, Assistant M.O.H. for the Port of London, by permission of Dr. Herbert Williams, M.O.H. We may take the opportunity to express our thanks to both of these gentlemen for their kindness and trouble in the matter.

The method employed was as follows :—

A large supply of Belfast tap water was saturated with air at the temperature of the laboratory, by means of a water vacuum pump so arranged as to cause air to bubble through in a rapid stream. The aeration lasted for six hours a day and was continued on three successive days.

Samples of this water were then incubated at 80°F in partly filled open Winchesters (A) for 24 hours and (B) for 48 hours.

Determinations of the dissolved oxygen in these were then made by the volumetric process.*

(A) was found to contain	5·79 c.c. per litre
(B) was found to contain	5·76 ,, ,,
Dittmar's figure for distilled water saturated with air at 27°C	5·77 ,, ,,

It was therefore assumed that the water incubated for 24 hours at 80°C contained the correct air saturation amount for that temperature and that it was not changed by further incubation.

In the experiments on the action of the mud samples, the procedure was similar to that already described by Mr. McKee. That is to say a series of stoppered litre bottles were nearly filled from the large stock of water (aerated at ordinary temperatures) and incubated without stoppers for 24 hours at 80° F.

For each experiment a quantity of the mud sample was weighed out equivalent to 12·5 grams per litre of water, and by means of a wash bottle full of the incubated water and a glass pestle, washed quickly from the dish (after comminution by the pestle) into the bottle, which was then filled to the brim, stoppered, and placed in the incubator. The contents of each bottle were thoroughly agitated at hourly intervals (which was not done in the case of Mr. McKee's experiments.)

Finally after the given interval, the bottle was removed from the incubator and a sample of the water syphoned off for the dissolved oxygen determination, and later a duplicate was employed for the blank determination.

The analytical characters of the mud samples as well as their effects on de-oxygenating the water are shown in the following table.

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* *See* p. 221.

THAMES DREDGINGS.

Collected by Dr. W. W. Willoughby, Assistant M.O.H., by kind permission of Dr. Herbert Williams, M.O.H., for the Port of London.

Date of Collection (1906).	No.	Where Sample was Collected.	Percentage Loss on Ignition. *	Percentage of Nitrogen. *	Probable Percentage of Sewage Sludge. *	Remarks.	Loss of Dissolved Oxygen caused by the sample in Tap Water saturated with Air at 80° F.						
							Weight of Mud per Litre.		Hours of Contact.	Dissolved Oxygen per Litre.			
							Wet.	Dry.		Originally present.	After period of Contact.	Actual Loss.	Percentage Loss.
July 17	1	Barge House, North Woolwich	3·48	0·048	1·3	Coarse grey sand, showing a few black patches on keeping; odour like paraffin	—	—	—	—	—	—	—
						Contained coal and cinders. On igniting scarcely blackened and no visible vapours	—	—	—	—	—	—	—
,,	2	Barking, near Outfall, North Side of Channel	11·69	0·388	13·9	Almost black mud; odour tarry; dried to a hard, grey cake, difficult to powder	12·5	4·38	3	5·77	1·74	4·03	69·8
						On igniting blackened and emitted odour with slight visible vapour	,,	,,	6	5·77	0·42	5·35	92·7
,,	3	Crossness, Half-way Reach, below Outfall	7·01	0·195	6·7	Almost black mud; odour tarry, dried to grey cake which powdered easily	12·5	3·32	3	5·77	3·27	2·50	43·5
						On igniting blackened and emitted odour, but no visible vapour	,,	,,	6	5·77	1·35	4·42	76·6
June 18	4	Greenhithe, North of Mid-Channel	11·76	0·382	13·7	Dark grey to black mud; no special odour; dried to grey cake, difficult to powder	12·5	3·59	3	5·77	2·16	3·61	62·6
						On ignition blackened and emitted vapours with distinct odour	,,	,,	6	5·77	1·11	4·66	80·8
,,	5	Mucking, South of Mid-Channel	1·43	0·015	0·1	Coarse grey sand, showing a few black patches on keeping	—	—	—	—	—	—	—
						On igniting only slight darkening and no visible vapour	—	—	—	—	—	—	—
,,	6	Chapman Light - -	1·34	0·015	0·1	Coarse grey sand, with some pebbles and shells. On igniting behaved like the Mucking sample	—	—	—	—	—	—	—

* On dry samples (*see* pp. 225–226).

The preceding experiments indicate that the dissolved oxygen present in a given water may disappear with considerable rapidity if the water is in contact with foul mud, and there can be no question, we think, that this is a point of considerable practical importance in relation to rivers like the Thames, Humber, Usk, etc., which, as elsewhere stated, are very muddy and contain sewage solids. It seems probable that the low amount of dissolved oxygen found in the more polluted portions of these streams is due quite as much to presence of these solids as to the liquid parts of the sewage discharged into them.

The importance of this point in relation to fishery streams is obvious.

(3) THE DESTRUCTION OF NITRATES BY FOUL MUDS.

It is well known that nitrates are destroyed when in contact with a putrefying liquid, and one of us has made a somewhat extensive series of experiments on the subject—partly alone and partly in collaboration with others*—with the object of removing nitrates from sewage effluents, so as to deprive the latter of their fertilising properties as regards green sea weeds.

We thought it of interest to ascertain whether foul mud would also destroy nitrates.

The experiments were entrusted to Mr. J. L. McKee, B.A., who employed the same mud samples as he had used in his experiments on the deoxygenation of water which are described above.

The following is an account of his work :—

"*Series* 1.—Twenty grams wet mud (Sample 1) were weighed into a stoppered bottle and 200 c.c. of the effluent from Sprinkler No. 1, Belfast Sewage Works, added.

The bottle, which was about three-quarters full, was then well shaken and put into an incubator at 80° F. during the period of the experiment. At the end of this period the nitrates present were determined by reduction with zinc-copper couple and subsequent nesslerisation. The mud contained 53·2 per cent. moisture, so that in each bottle there were—

9·36 grms. dry mud
10·64 „ water
200 c.c. sprinkler effluent

at the beginning of an experiment.

Before commencing the above series of experiments, a determination of nitrate present in the sprinkler effluent was made (with the zinc-copper couple), when it was found to contain 1·74 parts nitric nitrogen per 100,000.

In filling the bottles 200 c.c. of this effluent were diluted by the water in the mud to 210·6 c.c. and therefore contained $1{\cdot}74 \times \frac{200}{210{\cdot}6} = 1{\cdot}65$ parts nitric nitrogen per 100,000.

The following are the results obtained :—

Period of Incubation.	Parts of Nitric Nitrogen per 100,000.
0 hours	1·65
16 „	1·07
32 „	0·20
48 „	0·16

In the last two experiments of the series the possible error was about 0·05, and therefore very large in comparison with the amount found.

Taking the quantity of nitric nitrogen originally present as 100, the results are—

Period of Incubation.	Nitric Nitrogen.
0 hours	100
16 „	63·6
32 „	12·1
48 „	9·7

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* *See* pp. 182–191.

Series 2.—The experiments on the destruction of nitrates by mud sample 2 were performed in the same way, but 200 c.c. of a solution of potassium nitrate of known strength were used instead of the 200 c.c. of the sprinkler effluent. The mud contained 74·6 per cent. moisture, and therefore in each bottle at the beginning of an experiment there were—

5·08 grms. dry mud,
14·92 ,, water, and
200 c.c. nitrate solution.

TABLE OF RESULTS.

Period of incubation.	Parts nitric nitrogen per 100,000.	Percentage of nitric nitrogen.
0 hours	1·91	100
16 ,,	1·64	86
32 ,,	·16	8·6
48 ,,	·06	2·2

These experiments show that nitrates are reduced with considerable rapidity by foul mud deposits."

4.—Evolution of Ammonia from Foul Muds.

This is a question of importance in relation to the growth of green seaweeds and especially to that of the *Ulva latissima* (*see* Section 3, p. 139), and was of particular interest in connection with Belfast Lough (*see* Section 7A, p. 227), the sewage of the city having been poured into the Lough in the crude state for a number of years, with the result that parts of its bed now contain an abundance of sewage solids.

A scheme of sewage purification is at present being carried out which will get rid practically of the whole of the solids and of most of the ammonia. From the experimental evidence, it is this ammonia which has caused the growth of the green seaweeds in such abundance, the latter occasioning a serious annual nuisance when they drift ashore and putrefy.

The purification of the sewage ought then to lead, if not to the entire suppression, at least to a very substantial abatement of the seaweed nuisance.

But if the sewage solids which have been thrown into the Lough in previous years slowly evolve ammonia, the seaweed nuisance will probably continue until that ceases.

It was therefore decided to submit the question of ammonia evolution from foul muds to investigation, and the work was entrusted to Mr. J. L. McKee, B.A., who carried out the following experiments, with the same mud samples as he had used in his previous work on dentrification and deoxygenation. The following is an account of his work :—

"*Series* 1.—Quantities of wet mud (Sample 1) were weighed into three stoppered bottles, each of about 250 c.c. capacity, such that when filled to the brim with sea water they contained 20 grams of the mud per 100 c.c. The bottles were labelled 1, 2 and 3, and samples for analysis were always taken from 1.

The latter, from which the portion for analysis had been taken, was then filled up from 2, which was in turn filled up from 3. Thus 1 and 2 were kept out of contact with air and very little of the liquid in 3, which no doubt gradually became aerated, reached the bottle from which the samples for analysis were taken.

10 c.c. was the quantity withdrawn in all the determinations of the free ammonia, except the last two, where 5 c.c. were taken.

The bottles were kept at the ordinary temperature of the laboratory, and were well shaken from time to time.

The first determination was made as soon as the mud had settled, and as those subquently made were performed in exactly the same manner, the first alone will be described in detail.

10 c.c. of the clear supernatant liquid in 1 were transferred by a pipette to a distilling flask, 200 c.c. ammonia-free water added and 100 c.c. distilled over.

The distillate was then nesslerized in the usual way. The free ammonia in the sea water used was also determined, and the amount found has been deducted from the results of the analysis of bottle 1 shown below.

The moisture in the mud taken was determined by drying a weighed portion at 110° C. until the weight became constant.

The moisture found amounted to 55·9 per cent.

The bottles, therefore, contained $\frac{20 \times 44 \cdot 1}{100} = 8 \cdot 82$ grms. of dry mud per 100 c.c. of mixture.

TABLE OF RESULTS.

——	Date.	Time.	Interval in days since series was started.	Parts of ammoniacal nitrogen per 100,000.
	1905.			
Sea water - - - - - -	—	—	—	0·01
Bottle 1 - - - - - -	November 30	3 p.m.	0	1·37
„ - - - - - -	December 1	3 p.m.	1	1·5
„ - - - - - -	„ 4	3 p.m.	4	2·54
„ - - - - - -	„ 7	4.30 p.m.	7·05	3·07
„ - - - - - -	„ 11	11 a.m.	10·8	3·69
„ - - - - - -	„ 14	9.30 p.m.	14·25	5·13
„ - - - - - -	„ 18	11 a.m.	17·8	5·74
	1906.			
„ - - - - - -	January 9	—	40	5·99

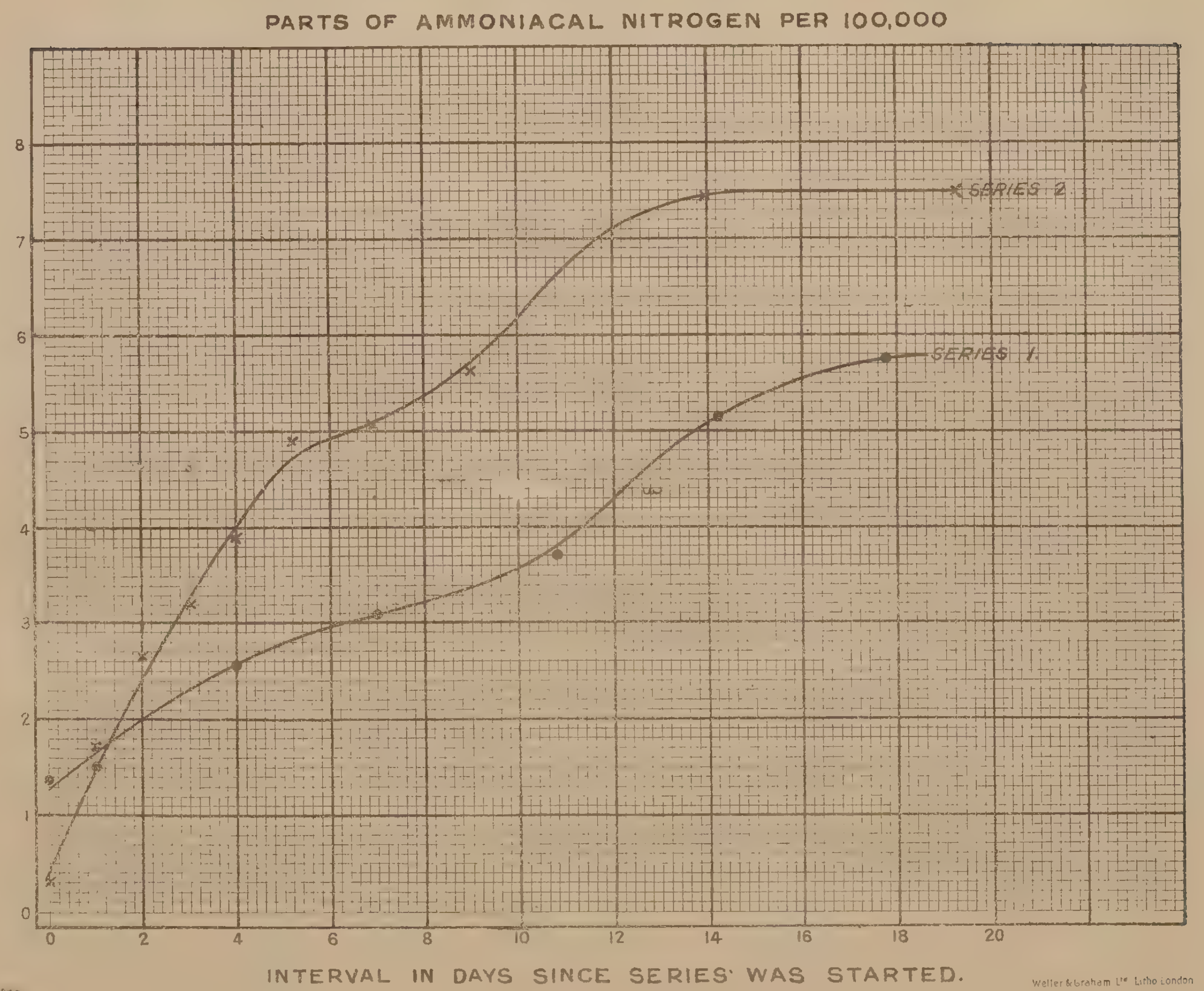
These results have been plotted on squared paper and the curve shows a curious diminution in the rate at which the ammonia was evolved about the seventh day from the commencement of the series (*see* curve attached).

This will be referred to again when the curve for sample 2 is being discussed. At the end of the series 8·82 grms. (calculated as) dry mud had evolved 0·006 grms. ammonia, or 0·068 per cent.

The mud contained 0·447 per cent. nitrogen, so that rather more than one-seventh, or 15·21 per cent., of this had been evolved as ammonia.

Series 2.—The same methods and quantities as were used in the case of Sample 1 were also employed with Sample 2, but the bottles were kept in an incubator at 80° F. and the first determination made immediately after they were filled. In making this first determination 10 c.c. were withdrawn from bottle 3 by a pipette and washed into the distilling flask through a filter by means of 200 c.c. ammonia-free water. 100 c.c. were then distilled and the distillate nesslerized in the usual way. The result obtained in this first estimation has been deducted from the results of the analyses of bottle 1 shown below.

EVOLUTION OF AMMONIA FROM FOUL MUDS.



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Weller & Graham Ltd Litho London

TABLE OF RESULTS.

——	Date.	Time.	Interval in days since series was started.	Parts of ammoniacal nitrogen per 100,000.
	1906.			
Sea water - - - - - -	January 15	—	—	0·01
Bottle 1 - - - - - -	„ 15	12 a.m.	0	0·03
„ - - - - - -	„ 16	„	1	1·72
„ - - - - - -	„ 17	„	2	2·64
„ - - - - - -	„ 18	„	3	3·18
„ - - - - - -	„ 19	„	4	3·88
„ - - - - - -	„ 20	5 p.m.	5·2	4·91
„ - - - - - -	„ 22	12 a.m.	7	5·01
„ - - - - - -	„ 24	„	9	5·63
„ - - - - - -	„ 29	„	14	7·48
„ - - - - - -	February 3	7 p.m.	19·3	7·48

The mud contained 74·6 per cent. moisture, therefore in each bottle there was a quantity containing $\frac{20 \times 25{\cdot}4}{100} = 5{\cdot}08$ grms. dry mud per 100 c.c.

Thus 5·08 grms. (calculated as) dry mud had evolved 0·00748 grm. ammonia, or 0·147 per cent.

This mud contained 0·99 per cent. nitrogen, so that rather more than one-seventh of this was evolved as ammonia.

By comparing this with the result on page 136 it will be seen that almost the same proportion of the total nitrogen was evolved as ammonia in the two cases.

The exact figures are :—

Percentage of total nitrogen evolved as ammonia	Sample 1 - -	15·2 per cent.
	„ 2 - -	14·8 „

From the curve attached it will be seen that the rate at which the ammonia was evolved decreased considerably between the fifth and ninth days, and afterwards increased. A similar result was obtained before (page 136), but as the bottles were not incubated it might have been due to changes in the temperature.

In this case, however, no such explanation can be advanced.

Certain changes in the appearance of the liquid in bottle 3, which contained an increasing amount of air as the series of determinations proceeded, perhaps throw some light on this point.

After a short time (about two days) a white scum formed on the surface of the liquid.

This was broken up each time the bottle was shaken, but always formed again. It was there on the fifth day, but on the following day it had not returned and the liquid was quite turbid and remained so during the time the experiments lasted.

These facts point to a bacteriological explanation, but more cannot be said in the present state of the investigation.

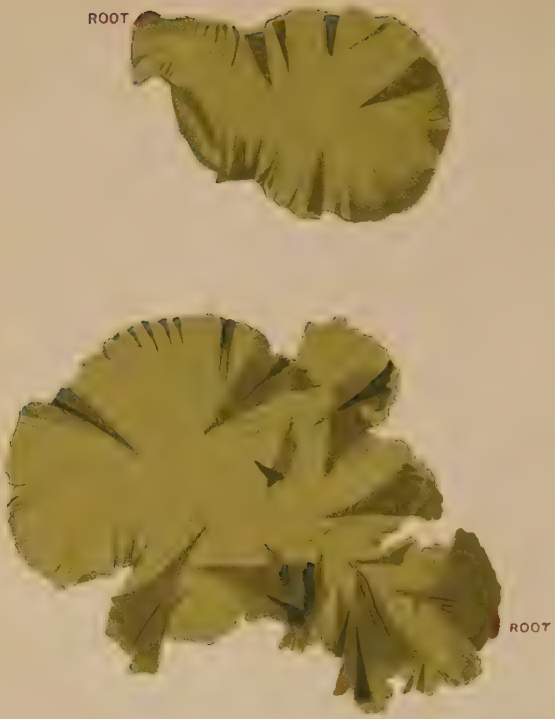
On January 24th the ammonia in bottle 2 was estimated at the same time as the ammonia in bottle 1. The difference between the two results was less than the error of experiment, so that the partly aerated liquid introduced from time to time from bottle 3 apparently did not affect the ammonia evolution in bottle 2 appreciably."

E. A. L.

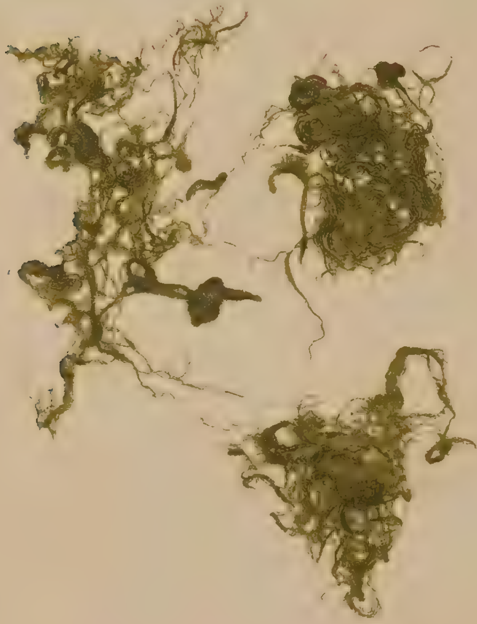
SECTION 3.

NUISANCES CAUSED BY CERTAIN GREEN SEAWEEDS AND INDIRECTLY BY SEWAGE.

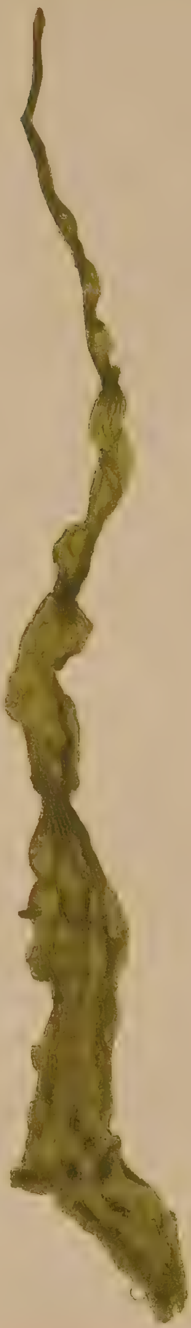
SOME GREEN SEA WEEDS
(PRESSED SPECIMENS)



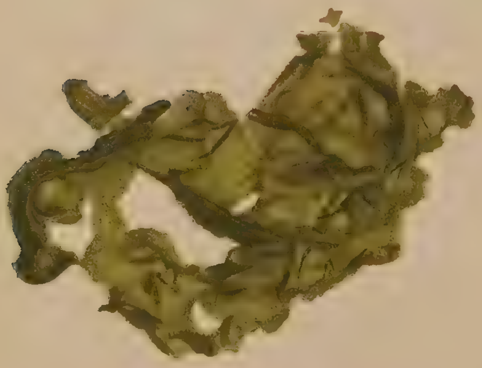
ULVA LATISSIMA – Young Fronds



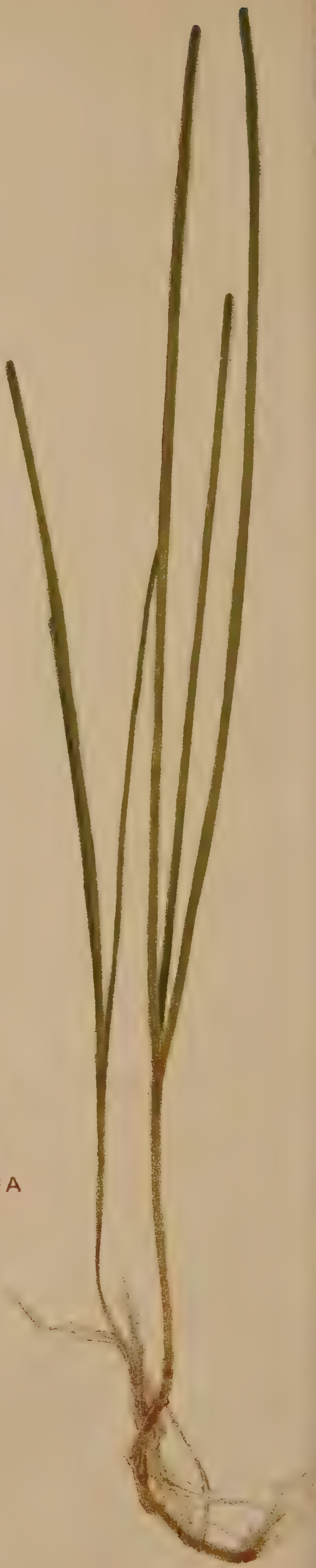
ENTEROMORPHA COMPRESSA
(GROWING IN SEWAGE EFFLUENT)



ENTEROMORPHA INTESTINALIS



ENTEROMORPHA INTESTINALIS
(GROWING ON CONTACT BEDS)



ZOSTERA MARINA
(SEA GRASS)

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Weller & Graham, L^td Litho

NUISANCES CAUSED BY THE GROWTH IN LARGE QUANTITIES AND SUBSEQUENT DECAY OF CERTAIN GREEN SEAWEEDS.

In certain sea-side localities a nuisance at times of considerable magnitude is produced by the decomposition of masses of green seaweed, chiefly of the species *Ulva latissima*, but also of certain varieties of *Enteromorpha*, such as *E. compressa* and *E. intestinalis*, and as will be shown, there is every reason to believe that the growth of these seaweeds in quantity, and especially that of the *ulva*, may be traced to the pollution of the waters in which they are found, by sewage. For a number of years a most serious nuisance of this kind has occurred in the upper reaches of Belfast Lough during the summer and autumn, the stench at low tide being often quite overpowering, and the air heavily charged with sulphuretted hydrogen.

A precisely similar nuisance, though not of the same magnitude, arises from the same seaweeds deposited on the sloblands in the northern portions of Dublin Harbour. At Southampton it occurs to a very considerable extent, more especially in the estuary of the Test River, and from our observations on the South of England coast, we believe that it must also be found occasionally at several other places, such as Plymouth (Plym Estuary), Falmouth, Exmouth, etc.

At Chichester we have observed these green seaweeds in abundance, and we are under the impression that the nuisance they have given rise to has been mistaken for a nuisance caused directly by sewage, which has led to litigation.

From the replies to the circular letter (*see* Appendix) it will be seen that a nuisance from this cause has also occurred at Barmouth, Cromer, Margate, Penzance, Southend-on-Sea (Southchurch Beach) and Teignmouth.* Among smaller localities, Robin Hood's Bay has been mentioned † in Yorkshire—a small fishing village, where this seaweed (*ulva*) occurs in large quantities, is most offensive, and the smell at times almost unbearable, the whole sewage from the village discharging into the sea near the seaweed.

This nuisance has, we believe, been often attributed to actual sewage matters deposited on the shore, but, as will be shown, there can be no question whatever that the varieties of green seaweeds named above can of themselves give rise to a nuisance of a similar character to that arising from foul sewage.

The attention of one of us was first directed to this matter from the serious nuisance occurring in the upper reaches of Belfast Lough where green sea-weeds grow in abundance and especially the *Ulva latissima*, which in windy weather is washed ashore often in enormous quantities, forming banks which are frequently two or three feet thick, and extend at times for miles along the coast, especially on the southern side.

Once deposited, these layers of weed often remain more or less stationary in the shallow bays or pools of the neighbourhood for months, and under these circumstances, and particularly in warm weather, rapid putrefaction occurs, and a perfectly intolerable stench arises, which is perceptible over a wide area, and seriously affects, not only the comfort of the inhabitants of the district, but the value of their property also.

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The investigation,‡ the results of which are described in the following pages, was originally undertaken with the view merely of ascertaining the cause of the nuisance arising from the sloblands of Belfast. But the inquiry gradually became more extended and eventually embraced not only a study of the chemical changes which occur when *Ulva latissima* ferments, but in addition, an examination of the composition and characters of the weed itself, the isolation of the products of its fermentation, and attempts to isolate the particular organisms giving rise to these products; and finally endeavours have been made to ascertain, both experimentally and by an examination of localities in which the seaweeds are either present in quantity or from which they are virtually absent, the relationship of *Ulva latissima* to the pollution of sea water by sewage.

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* The probability of a nuisance occurring at this place there can be no doubt of, as the *ulva* is very plentiful in the estuary of the Teign River.

† Hill. Interim Report of Royal Commission on Sewage Disposal, Vol. II [Cd. 686.]

‡ The following papers have been published on the subject :—
Letts and Hawthorne, *B.A. Reps.* (Bradford), 1899.
" " " *Proc. Roy. Soc* Edinburgh, 1899–1901.
" " " *B.A. Reps* (Glasgow), 1901.
" " Totton, " (Southport), 1903.
This section of our Report has been compiled partly from the above, and partly from work which has not been published. But the greater part has been taken from the second of the papers mentioned above.

For the sake of clearness and convenience the results of the inquiry into these different questions will be given in a somewhat different order from that in which they were originally obtained.

THE CHEMICAL CHANGES WHICH OCCUR WHEN CERTAIN GREEN SEAWEEDS FERMENT.

A nuisance arises from these seaweeds only when they are crowded together in such quantities that they are unable to exercise their natural functions (*see* p. 164), and when they are submerged in water, or at least constantly saturated with water. When dried they are quite inoffensive, and when not crowded together they grow vigorously in sea water, even under what would at first sight appear to be most unfavourable conditions. This is especially the case with the *ulva*, which continues its growth when uprooted, and even when its fronds are torn by the battering action of waves and extensively perforated by the small gasteropods and other marine animals which feed on them.*

The course of events when a nuisance is produced from these green seaweeds is as follows. During high winds or gales they are washed towards the shore† and are eventually deposited in the shallows in layers, which, in Belfast Lough, vary from a few inches in thickness to two or even three feet.

As the tide falls these layers are left in a waterlogged condition, and are again submerged by the incoming tide. They are thus kept constantly moist, and in warm weather soon putrefy. The fronds first become flabby, then gradually darken in colour, while a peculiar sickly smell is disengaged. Later the whole mass becomes a black pulp, from which sulphuretted hydrogen is freely disengaged, and later still a white or grey coating (presumably of sulphur) makes its appearance, the mass below degenerating into black mud which is exceedingly foul, and has all the characteristics of sewage sludge.

Experiments conducted in the laboratory on the exact nature of the fermentative changes led to the following results.

A quantity of the fresh seaweed was carefully washed in several changes of ordinary tap water until free from shells and debris of various kinds,‡ and it was then distributed between two flasks, one of which was filled with tap water and the other with sea water, care being taken to get rid of all air adhering to the weed. A well fitting (paraffined) cork was then attached to each of the flasks, and through the cork a gas delivery tube passed, which dipped into a small mercury pneumatic trough and under an inverted test-tube full of mercury. The flasks, with their attachments, were then left in the laboratory at ordinary (winter) temperatures.

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* The vitality of this green seaweed is very remarkable, as the following notes will show:—

"The seaweed had been somewhat roughly treated. Originally collected near Dublin, the fronds were rolled into packets and sent by post to Belfast. By an accident they were left uncared for on their arrival for a week, and when examined several of them were found to be in an incipient state of decomposition. Some, however, appeared to be still healthy. These were well washed with tap water, trimmed with scissors (for cutting the seaweed does not appear to affect its vitality), and the pieces placed in fresh water in glass dishes. The experiments on their powers of ammonia absorption were made six or seven weeks after they had been collected," and this sample of seaweed remained quite healthy for a year afterwards, although the water in which it was immersed was not once changed.

In more recent investigations samples of the *ulva* were collected (in the detached condition) in the summer of 1904 and served for a number of experiments then. They were left untouched for a year in a glass dish merely covered with a sheet of glass and placed on the sill of a window having a northern aspect. A year later the fronds appeared quite healthy (although the water had not been changed), and the experiments recorded on p. 159 were made with them.

† Under favourable conditions the *Ulva latissima* grows to an extraordinary size—fronds over three feet long and between one and two feet broad having frequently been found with attached roots in some salt marshes in the northern part of Dublin Bay, where (relatively speaking) they were not liable to disturbance by wave action. But in Belfast Lough most of this seaweed is found in a detached condition, and probably is uprooted when quite young by wave action.

‡ The seaweed, as obtained from the Belfast foreshore, was nearly always infested with minute spiral shell-fish, which feed upon it and eat out circular holes.

After some six weeks the contents of the flask containing the *ulva* and sea water began to evolve gas, and a few days later they blackened, while those of the flask containing *ulva* and tap water gave off gas some days later, and no blackening subsequently occurred.

Some of the liquid from the first flask was driven over along with the gas, and when the test-tube became full of the latter, the liquid escaped on to the surface of the mercury in the pneumatic trough. It was found to be strongly acid, and as it evaporated, smelt of butyric acid. The gases from this flask were examined after an interval of about three months had elapsed since starting the experiment, and were found to consist mainly of hydrogen, carbonic anhydride, sulphuretted hydrogen, and nitrogen.

These preliminary experiments gave a distinct clue to the nature of the chemical changes which the weed suffers when it rots on the foreshore in a moist condition, as well as to the cause of the nuisance to which it then gives rise.

It is clear that an acid is produced in the first stage of the fermentative processes, while at a later period, and probably by a distinct fermentative act, sulphides and sulphuretted hydrogen are formed, either by the reduction of the sulphates present in the weed itself or in the sea water, or from the albuminoid substances contained in the former—these sulphides reacting on the iron compounds in the tissues of the weed to give ferrous sulphide. The latter would, no doubt, be attacked by the acid, with evolution of sulphuretted hydrogen, and thence the nuisance (*see* p. 126). As a result of these preliminary experiments, it was decided to investigate the quantitative composition of the gases evolved from the fermenting *ulva*, and also to isolate and identify the butyric acid.

To obtain the gases, the same arrangement was employed as before, only the flasks were placed as soon as charged, in an incubator at blood heat. Under these circumstances gases began to come off in forty-eight hours, and were then rapidly evolved.

The following analyses were made :—

ANALYSIS OF GASES EVOLVED FROM ULVA LATISSIMA FERMENTING IN SEA WATER.

	I. (Collected 5 days after incubation, at 37°C.)	II. (Collected 12 days after incubation at 37°C.)
Volume of gas taken	14·0 c.c.	16·55
After addition of potash	8·0 „	8·45
„ pyro	8·0 „	8·45
Oxygen then added	13·7 „	11·55
After explosion	10·0 „*	7·65*
CO_2 found	6·0 c.c.	8·10
O_2 „	none	none
H_2 „	7·8 c.c.	8·23
N_2 „	0·2 „	0·22
	14·0 c.c.	16·55
Percentage composition.		
CO_2	42·8 c.c.	48·94
H	55·7 „	49·73
N^2	1·5 „	1·33
	100·0 c.c.	100·00

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* The gas remaining after explosion contained no CO_2.

No sulphuretted hydrogen was present in the gases, which, as their analyses indicate, consisted entirely of carbonic anhydride and hydrogen. Owing to the solubility of carbonic anhydride in water, it was to be expected that the gases collected at first would contain a lower proportion of this constituent than was actually evolved. Only when the liquid in the flask had become saturated with carbonic anhydride would the gaseous products of the fermentation make their way into the collecting tube in their proper proportions, and this state appears to have been reached when the second analysis was made. Its results show the carbonic anhydride and hydrogen to be present practically in the same proportions by volume or in equi-molecular proportions.

The fermentation of grape sugar by the *Bacillus butyricus* is usually represented by the equation

$$C_6H_{12}O_6 = 2CO_2 + 2H_2 + C_4H_8O_2$$

and, as already mentioned, before any gas analyses had been made the production of butyric acid had been indicated.

A qualitative examination of the contents of the flask after fermentation gave further evidence of the production of the acid, for on distilling them with sulphuric acid an acid liquid passed over, and this, when neutralised with soda and evaporated to dryness, gave a solid residue, which, when warmed with strong sulphuric acid, emitted a distinct odour of butyric acid. Also when it was warmed with strong sulphuric acid and alcohol, the characteristic odour of butyric ether became apparent.

We should probably not have pursued the question further had it not been for the results of a quantitative analysis of what we supposed to be calcium butyrate obtained as follows :—

Some of the *ulva* was well washed and packed into a flask, which was then filled with sea water and the mixture fermented in an incubator at 37°C. until gas evolution ceased. The liquid was then strained off from the seaweed through a cloth filter, distilled with sulphuric acid, the distillate boiled with excess of calcium carbonate, filtered, and evaporated to dryness. Weighed portions of the carefully dried residue were then ignited with strong sulphuric acid, with the following results :—

0·2546 grm. gave 0·1883 grm. $CaSO_4$ = 0·0554 grm. Ca = 21·75% Ca.
0·3695 „ 0·2681 „ = 0·0788 „ = 21·34 „
Anhydrous calcium acetate requires 25·32 „
„ „ propionate requires 21·50 „
„ „ butyrate „ 18·70 „

These results indicated that propionic and not butyric acid had been produced, and the matter seemed worth further investigation, as there appears to be some doubt as to a propionic fermentation from crude vegetable substances, and it is certainly not mentioned in modern chemical or bacteriological text-books. On the other hand, in the older chemical works such a fermentation is mentioned. Thus in Wurtz's *Dictionnaire de Chimie* the following statements are made under the article *Acide Propionique* :—

(1) Redtenbacher obtained propionic acid by exposing glycerine and yeast for several months at 20–30°C. [*Liebig's Annalen*, 57 (1845), p. 174.]

(2) Keller, by fermenting bran and scraps of leather with chalk. [*Liebig's Annalen*, 73 (1850), p. 205.]

(3) Putrefaction of peas or lentils gives propionic and butyric acids. [Boehme, *Journ. prakt. Chem.*, 40 (1847), p. 278.]

(4) Fermentation of calcium tartrate. [Noellner, *Liebig's Annalen*, 38 (1841), p. 299. Nicklès, *ibid.*, 61 (1847), p. 343. Dumas, Malaguti, and Leblanc, *Comp. Rend.*, 25 (1847), p. 781.]

(5) Propionic acid is stated to be produced by the fermentation of glycerine and of sugar under certain circumstances. [Strecker's *Lehrbuch der organischen Chemie*, 5th edition (1867), p. 159.]

While in Richter's *Organic Chemistry* (English translation, 1900) none of these methods are mentioned, the only process of a similar kind for the production of the acid there alluded to being the fermentation of calcium malate and lactate.

It was therefore decided to prepare a quantity of the acid or acids which the fermenting *ulva* gives rise to, and to submit them to a careful examination.

Accordingly, a considerable quantity of the well-washed seaweed was fermented with sea water at 37°C. in large flasks until no further evolution of gases occurred, which required about fourteen days. The resulting fluid was drained off from what remained of the seaweed and distilled with dilute sulphuric acid until traces of hydrochloric acid began to come over. The distillate was neutralised with caustic potash and evaporated to dryness, when about 25 grms. of solid residue were obtained. Experiments with weighed quantities of a known sample of potassium butyrate, indicated that the best method for extracting the acid was to treat a strong aqueous solution of the salt with sulphuric acid, and then to extract with ether; distillation of the dry salt with concentrated sulphuric acid leading to considerable charring and loss.

The dried residue was therefore dissolved in 80 c.c. of water, the resulting solution filtered and mixed in a separating funnel with 40 c.c. of strong sulphuric acid, when an oily liquid rose to the surface. The contents of the separating funnel were then extracted six times with well-washed ether, the ethereal extracts filtered and distilled from a water-bath.

The remaining liquid was submitted to fractional distillation, and after three fractionations, the bulk distilled over between 140–150°C. The lower boiling portions were treated with phosphoric anhydride and separately fractionated.

They yielded three fractions, which were collected at the following temperatures :—

(1) 110°–125° (2) 125°–150° (3) 150°–165°

The main portion of the distillate from the first fractionation weighed 4·7 grms., and had an odour which closely resembled that of a known sample of propionic acid.

It was boiled with water and barium carbonate until neutralised, the resulting solution filtered and evaporated on a water-bath to a syrup. Its behaviour now was curious. Some of the syrup was dissolved in a little alcohol and ether was then added, when it was reprecipitated apparently in the same condition. A drop of the syrup exposed for several hours also dried up to a gummy mass which refused to crystallise. But the main quantity of syrupy liquid suddenly solidified on stirring. The resulting crystalline mass was washed with cold alcohol two or three times and was then dried. It behaved in precisely the same way as a known specimen of barium propionate. Thus it readily dissolved in cold water; and on adding alcohol to a concentrated solution thus obtained, brilliant crystals separated out, which, when examined under the microscope, had very characteristic forms, being either quadratic octohedra or combinations of the octohedra with quadratic prisms. Its analysis, however, showed that it contained small quantities of an impurity which obstinately adhered to it, as the following figures show :—

Analysis of Barium Salt dried at 100°C. *until of constant weight.*

(1) 0·5153 grm. gave 0·4190 grm. $BaSO_4$ = 0·2464 grm. Ba = 47·8% Ba.

[The salt had been washed several times with cold alcohol.]

(2) 0·2000 grm. gave 0·1623 grm. $BaSO_4$ = 0·09543 grm. Ba = 47·71% Ba.

[The salt, after washing with cold alcohol, had been boiled with alcohol.]

(3) 0·2648 grm. gave 0·2156 grm. $BaSO_4$ = 0·1268 grm. Ba = 47·87%Ba.

[In addition to the treatment to which (2) had been submitted, this portion of the salt had been recrystallised from water by the addition of alcohol.]

(4) 0·3216 grm. gave 0·2622 grm. $BaSO_4$ = 0·1542 grm. Ba = 47·93%Ba.

[This salt was obtained from the mother liquors of (3), but was recrystallised from water and alcohol.]

Obtained :—		Calculated for :—	
(1) - -	47·80	$Ba(C_2H_3O_2)_2$ - -	53·72
(2) - -	47·71	$Ba(C_3H_5O_2)_2$ - -	48·41
(3) - -	47·87		
(4) - -	47·93	$Ba(C_4H_7O_2)$ - -	44·05

In order still further to identify the propionic acid, a quantity of the silver salt was obtained by decomposing a solution of 2 grams of the barium salt with the equivalent quantity of silver nitrate. The resulting white precipitate was washed on a filter until the washings gave no precipitate with sulphuric acid, and crystallised from hot water.

Analysis of Silver Salt dried in the desiccator.

(1) 0·232 grm. gave on ignition 0·1305 grm. Ag=56·25%.

(2) 0·0720 grm. „ „ 0·0400 „ =55·55%.
[obtained from the mother liquors of No. 1].

(3) 0·3633 grm. gave on ignition 0·2141 grm. Ag=58·98%.
[obtained by further evaporation of the mother liquors from No. 2]

% Ag obtained :—		% Ag calculated for :—	
(1) - -	56·25	$AgC_2H_3O_2$ - -	64·66
(2) - -	55·55	$AgC_3H_5O_2$ - -	59·66
(3) - -	58·93	$AgC_4H_7O_2$ - -	55·38

It is evident from these figures that some butyrate clings obstinately to the propionate, and owing to its relative insolubility is precipitated first, the bulk of the propionate being found in the mother liquors.

A qualitative reaction was next employed for the identification of the propionic acid.

If this acid is boiled with excess of litharge and the solution allowed to remain in the cold for some time in contact with the litharge, a basic lead salt is produced, which is more soluble in cold than in hot water, and hence is precipitated on boiling the solution.

Comparative experiments tried both with a known sample of propionic acid and with some of the fraction mentioned above, boiling between 125°–150°, give precisely similar results when submitted to this test, a white powdery salt being precipitated from each.

The three fractions obtained from the lower boiling portions of the acids obtained from the fermenting *ulva* were examined as follows.

A roughly graduated pipette was made, and with it the same volume—about 0·2 c.c.—of each of the fractions was removed, weighed, diluted with water, titrated with $\frac{N}{10}$ baryta, the titrated fluid evaporated to dryness, and heated at 100°C. until of constant weight, then ignited with sulphuric acid, and the resulting barium sulphate weighed.

The following table contains the results, calculated in such manner as to be comparable both with each other and with the theoretical quantities required for acetic, propionic, and butyric acid respectively.

Fraction	Acid taken	c.c. $\frac{N}{10}$ Baryta required for 1 part of acid	Weight of dry Barium salt from 100 parts of acid	Percentage of Barium
110°–125° C.	0·2430 grm.	126·1	177·3	50·68
125°–150° „	0·2332 „	129·1	189·7	48·54
150°–165° „	0·2192 „	113·7	182·2	44·70
$C_2H_4O_2$	requires	167·0	212	53·72
$C_3H_6O_2$	„	135·0	191	48·41
$C_4H_8O_2$	„	113·6	181	44·05

Although these results are not entirely satisfactory or concordant, they certainly point to the occurrence of acetic as well as propionic and butyric acids among the products of the fermentation of *ulva* in sea water, but the identification of the former with certainty was not possible, owing to the smallness of the low boiling fraction and the difficulties attending the separation of a given acid of the fatty series from a mixture with its homologues. But the boiling point and higher specific gravity of the low boiling fraction, as well as the percentage of barium found in the barium salt obtained from it, can scarcely be accounted for except on the assumption that it contained acetic acid.

The above-described experiments on the fermentation of *Ulva latissima* in sea water thus afford evidence that at least three members of the fatty series of acids are produced : of these, however, propionic acid is formed in by far the largest quantity.

THE COMPOSITION OF THE TISSUES OF ULVA LATISSIMA.

The occurrence of the *ulva* in considerable quantities in localities where crude sewage makes its way into the sea, and the experiments just recorded on the products of its fermentation, raised several questions which rendered it advisable to make both an ultimate and proximate analysis of its tissues. Thus, if the growth of the seaweed in quantity is induced by pollution of the sea water by sewage, the seaweed itself might possibly be found to contain a higher proportion of nitrogen than is present in other species which luxuriate only in pure sea water.

Again, as regards the products of its fermentation. What substance present in its tissues gives origin to the propionic and other acids ? Is it a carbo-hydrate ; and if so, what carbo-hydrate, and whence come the ferrous sulphide and sulphuretted hydrogen which are produced abundantly in the later stages of the fermentation ?

Ultimate Analysis.

For the ultimate analysis a considerable quantity of the seaweed was collected, and each frond separately washed in tap water, and finally with distilled water. The seaweed was then drained, pressed between filter-paper, dried in the air, and then in a desiccator until it was quite brittle, when it was reduced to a fine powder in a mortar, and the powder then dried in a weighing bottle. All the different determinations were made on portions of the same stock of seaweed thus treated.

Ash.—To obtain the ash, weighed quantities of the seaweed were ignited in a platinum crucible at as even a temperature as possible until the residue was of constant weight. We give below all the results obtained, but may remark that (2) and (3) are probably too low, from loss of sodium or potassium chloride.

(1) 0·6502 grm. yielded 0·1001 grm. ash=15·39 %
(2) 0·4582 ,, ,, 0·0667 ,, ,, =14·56 ,,
(3) 0·4753 ,, ,, 0·0698 ,, ,, =14·68 ,,
(4) 0·4958 ,, ,, 0·0762 ,, ,, =15·37 ,,
(5) 0·3248 ,, ,, 0·0499 ,, ,, =15·36 ,,
Mean 15·07 %

Total Nitrogen—by Dumas' method.

(1) 0·5280 grm. gave 27·6 c.c. nitrogen at 16°C. and 764 mm.
=26·21 c.c. at N.T.P.=0·032836 grm.=6·22 %

(2) 0·1986 grm. gave 10·5 c.c. nitrogen at 19°C. and 764 mm.
=9·87 c.c. at N.T.P.=0·01237 grm=6·23 %

(3) 0·7122 grm. gave 36·6 c.c. nitrogen at 17°C. and 764 mm.
=34·63 c.c. at N.T.P.=0·043382 grm.=6·09 %
Mean=6·18 ,,

Carbon and Hydrogen.—The powdered seaweed was ignited in a closed combustion tube with chromate of lead.

$$\text{(1) 0·6127 grm. gave}\begin{cases}\text{0·2937 grm. } H_2O = \text{0·0326 grm. } H = \text{5·33 \%} \\ \text{0·7936 ,, } CO_2 = \text{0 2164 ,, } C = \text{35·32 ,,}\end{cases}$$

$$\text{(2) 0·6560 ,, ,,}\begin{cases}\text{0·3075 ,, } H_2O = \text{0·0342 ,, } H = \text{5·21 ,,} \\ \text{0·8413 ,, } CO_2 = \text{0·2294 ,, } C = \text{34·98 ,,}\end{cases}$$

Mean °/₀ of hydrogen = 5·27
,, carbon = 35·15

The composition of the tissues of *Ulva latissima* deduced from the preceding analysis is—

Carbon	35·15		
Hydrogen	5·27		
Nitrogen	6·18		
Oxygen (by difference)	38·33		
Ash	15·07 containing	Sulphur	3·21
		Iron	2·20
	100·00		

Further investigations regarding the composition of the tissues of the *ulva* have shown remarkable variations depending apparently on environment, and that some other green seaweeds resemble it in this respect. The following analyses were made by Mr. J. H. Totton, B.A., at the suggestion of one of us :—

COMPOSITION OF THE TISSUES OF CERTAIN GREEN SEAWEEDS.

Variety and Locality	Percentage of Nitrogen	Percentage of Ash
Ulva latissima—		
From contact beds *	8·94	9·41
,, Belfast Lough	6·18	15·07
,, Larne Lough †	3·01	29·00
Enteromorpha compressa—		
From a sewage effluent *	7·44	16·05
,, Larne Lough	1·96	28·60
Enteromorpha intestinalis—		
From brackish ponds near Belfast	1·58	51·78
,, Island Magee †	1·61	—

It will be seen that the proportion of nitrogen increases with the pollution, whereas that of the ash decreases.

Some further observations were also made in relation to the ash of the *ulva* and chiefly as regards the value of this seaweed as a manure.

The value of a manure, it need scarcely be said, depends upon several factors, of which the chief are the amount of nitrogen, phosphoric acid, and potash salts which it contains, and more especially of the two former. The analyses given above show that the *ulva* as it occurs in Belfast Lough (and, no doubt, in other places similarly situated), is a highly nitrogenous manure, and, therefore, an excellent one for certain agricultural purposes ; but no determinations had been made of the phosphoric acid which it contains, and it occurred to us that such determinations would be of interest, as well as those of some of the other inorganic constituents of the seaweed.

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* *See* p. 163.
† Unpolluted localities.

In order to make these analyses, it was necessary to first obtain the ash of the *ulva*, and two separate experiments made at different times showed that the ash is not always of the same nature. Thus a sample of the seaweed collected early in December, 1902, gave, when incinerated, a brown ash, whereas another sample collected later gave one which was much whiter.

On analysing the two, it was found that the *brown* ash contained 3·4 per cent. of phosphoric anhydride, equivalent to 0·51 per cent. on the dried seaweed itself, whereas the *white* ash contained 4·3 per cent., equivalent to 0·65 per cent. of the dried seaweed.

The amount of phosphoric anhydride in dry farmyard manure appears to vary from 0·7 to 1·4 per cent. So that the *ulva* may be considered to be equivalent to a poor sample of farmyard manure in respect of this factor, while greatly superior to it in relation to its nitrogen content—probably three times at least.

A further examination of the ash of the *ulva* for certain other constituents gave the following figures—

Silica	16·6	per cent.
Sulphuric anhydride	22·1	,, ,,
Magnesia	21·6	,, ,,
Oxides of iron and aluminum	11·6	,, ,,
Lime	9·4	,, ,,
Soda	4·0	,, ,,
Potash	3·9	,, ,,

PROXIMATE ANALYSIS.

The attempts which we have made to isolate any definite compounds as proximate constituents of the *ulva* have not been very successful, but it is only fair to say that we have not devoted much time to the matter.

Various experiments were tried with different solvents.

When boiled with water the seaweed does not soften nor suffer apparently any considerable change, and no blue colour is produced when the infusion is treated with iodine.

A special experiment was made to ascertain whether any carbohydrate was present capable of ready hydrolysis into a sugar, and for this purpose a quantity of the washed *ulva* was treated for a week in the cold with water containing 5 per cent. of sulphuric acid. The extract was then drained away from the seaweed, excess of barium carbonate added, the solution filtered and evaporated.

During the evaporation, white amorphous matter separated and oily globules also. The dried residue was treated with a little water, the solution filtered and heated on a water-bath with 2 grms. of crystallised phenyl-hydrazine hydrochlorate, and 3 grms. of sodium acetate, but no trace of a crystallised osazone could be obtained. For the sake of comparison, a mixture of 1 grm. of ordinary dextrose with the same quantities of phenyl-hydrazine hydrochlorate and sodium acetate and water was heated and gave abundance of the yellow osazone.

The amorphous matter turned out to be magnesium carbonate, with practically no organic matter.

The remainder of the *ulva*, after treatment with acid, was well washed with distilled water, and then digested in the cold for a week with 5 per cent. caustic soda solution. The resulting brown liquid was coloured green by a slight excess of hydrochloric acid, and a brownish flocculent precipitate was produced.

By treating the *ulva* with alcohol or ether, the chlorophyll, etc., are only very slowly dissolved. In a preliminary experiment some of the dry seaweed was submitted to the action of the boiling re-agents for a week, in an extraction apparatus—ether first and alcohol later, but at the end of that time it was still green in parts.

In a later experiment 14 grms. of the *ulva*—washed, dried, and roughly powdered—were boiled in a flask with inverted condenser for a week with alcohol. Each day the alcohol was filtered off and distilled from the same (tared) flask, the distillate being again employed for the extraction.

The dried alcoholic extract weighed 2·35 grms., or about 17 per cent. of the weight of the original dried seaweed.

What remained of the latter was then dried and digested in the cold for eight days with a 5 per cent. solution of caustic potash. The liquid was then filtered off through a weighed filter, and the residue of seaweed collected on the latter, well washed and weighed. It amounted to about 7 grms.

On the supposition that alcohol removed all the chlorophyll, fat, etc., and the caustic potash the albuminoids, the composition of the dried seaweed may be represented thus :—

Chlorophyll, fats, etc.	17	per cent.
Albuminoids or "proteids"	33	" "
Cellulose	50	" "
	100	" "

If the percentage amount of nitrogen found in the *ulva* be multiplied by the factor 6·25 (often employed for calculating in such cases the "Proteids or albuminoids"), the result is 38·6, which is not very different from 33, and it must be remembered that the experiment was only roughly quantitative.

BACTERIOLOGICAL EXAMINATION.

From the chemical examination of the products of the fermenting *ulva* it seemed probable that it was attacked by at least two different species of micro-organisms—the first producing fatty acids together with hydrogen and carbonic anhydride; the second causing the formation of sulphides.

The evidence on this point was tolerably clear, for on several occasions no sulphides were produced at all, and, as a consequence, no blackening of the weed occurred, and no evolution of sulphuretted hydrogen, although fermentation had been active, and fatty acids had been plentifully produced, together with hydrogen and carbonic anhydride. And in all the experiments in which the weed blackened, the acid-producing phase of the fermentation preceded that of the sulphide formation by a considerable interval.

Also, when the *ulva* was allowed to ferment in tap water and not in sea water, the production of sulphides was always delayed, and very often did not occur at all.

Numerous attempts have been made to isolate the organisms causing the two changes, but not with absolute success.

Stained preparations of the fermenting *ulva* showed that spore-forming bacilli similar in appearance to *B. tetani* were abundant, but all attempts to isolate them by Koch's plate method or Esmarck's roll tube (anaerobic) cultures, either with ordinary gelatine or agar media, failed, practically no colonies appearing.

A special culture fluid was then made with sea water containing 1 per cent. peptone and 1 per cent. glucose, and (after sterilisation) flasks of this were inoculated (A) with a droplet of the liquid from a tube containing fermenting *ulva* and sea water, and (B) with a minute fragment of the *ulva* itself from the same tube after its contents had been heated for twenty minutes to 80° C., to destroy all but spores.

These cultures when incubated grew, and showed, it was thought, some signs of gas evolution.

After five days agar plate cultivations were made from both, but no colonies appeared. Similar cultivations were made with a medium containing 1 per cent. peptone and 1 per cent. glucose with sea water and agar, both under aerobic and anaerobic conditions, but again without obtaining any definite growth of colonies.

On the other hand, the glucose peptone sea water medium which had been inoculated with a fragment of the fermenting weed, heated to 80° C., developed acid, the amount of which was determined by $\frac{N}{10}$ baryta solution.

10 c.c. after 3 days' incubation at 37° C. required 2·2 c.c. $\frac{N}{10}$ baryta=0·01628 grms. propionic acid.

10 c.c. after 7 days' incubation at 37° C. required 2·68 c.c. of $\frac{N}{10}$ baryta = 0·0198 grms. propionic acid.

An experiment was then made on a larger scale with this culture fluid, which was sterilised and inoculated with some drops of the liquid from a test-tube containing sea water, glucose, and peptone, and a fragment of the fermenting *ulva*.

The flask containing the inoculated fluid was provided with a cork and an arrangement for collecting any gases which might be evolved, and was placed in an incubator, where it remained for two or three weeks, but no appreciable quantity of gas came off. The contents of the flask were then distilled with sulphuric acid, the distillate boiled with excess of barium carbonate, and the filtered solution evaporated to dryness. A small quantity of a gummy barium salt remained, which qualitatively resembled the crude barium salt obtained from the fermentation of the weed, but its amount was not sufficient for any quantitative experiments.

Attempts were next made to obtain colonies of the micro-organism by employing a substratum of the weed itself. Some fronds of the *ulva* were pressed and dried, and then attached to glass plates by weak gelatine solution. The plates so prepared were next sterilised by heat, and three of them treated as follows :—

On No. 1, some sterilised gelatine solution was poured, previously inoculated with a droplet taken from a tube containing sea water and a fragment of *ulva* which had fermented but had not blackened. On No. 2 some sterilised agar was poured which had been similarly inoculated ; and on No. 3 the same medium, inoculated from the same source, which had previously been heated to 80° C. for twenty minutes.

Of these three plate cultivations, well-marked colonies appeared on Nos. 1 and 2. No. 3 was doubtful and too much dried up.

Two colonies from No. 1 and four from No. 2 were planted out in tubes containing fragments of *ulva* and sea water previously sterilised. In three days the tubes inoculated with No. 1 had given off a good deal of gas, and one of those inoculated with No. 2 had also given off gas and its contents were turbid. It seems probable, therefore, that by this method the organism causing the acid fermentation was isolated.

Regarding the second or sulphide-forming phase of the fermentation, as we have already said, it always occurred much later than the first or acid phase, and frequently did not take place at all ; and although the presence of sea water does not appear to be absolutely essential to its occurrence, yet undoubtedly it materially assists it, and for that reason we are inclined to believe that the sulphides owe their origin chiefly to sulphates in the water, and possibly in the *ulva* itself, and not to the albuminoids present in such abundance in the weed.

There is also some evidence to show that the organisms concerned in the process occur in the *mud* of the foreshore where the *ulva* is found, and not in the sea water.

The following experiment brings out these facts.

A number of test-tubes were partly filled with sea water, and others with tap water, and in each a piece of *ulva* was placed previously well washed in tap water, and all air bubbles adhering to the weed were got rid of by pressure with a glass rod.

A cotton-wool plug was then inserted in the mouth of each tube, which was made to support a strip of paper moistened with lead acetate, which hung about an inch above the surface of the liquid.

In addition to five such tubes containing the washed weed and sea water, and five containing the washed weed and tap water, two similar tubes were prepared containing *unwashed* weed, one with sea water and the other with tap water. All the tubes were then placed in the incubator. In 24 hours the acid phase of the fermentation had commenced in all the tubes, indicated by the inflation of the weed by the evolved gases.

In 48 hours the lead paper in the tube containing the *unwashed* weed and sea water had begun to blacken distinctly, and that containing the *unwashed* weed and tap water was also tinged, though faintly. In 72 hours the lead papers in all the sea water tubes were strongly blackened, but those in the fresh water tubes remained unaffected, except the one in the tube containing the unwashed weed. In 168 hours the unwashed weed in sea water was itself beginning to blacken, but the contents of the tap water tubes had still only faintly blackened their lead papers. Even after a month, the difference in the appearance of the contents of the two set of tubes was very noticeable.

Zelinsky* has described an organism which he named *Bacterium hydrosulfureum ponticum,* and obtained from the ooze of the Black Sea, which reduces sulphates to sulphides, and evolves sulphuretted hydrogen. He employed a special culture fluid for its growth, containing 1 per cent. solution of ammonium tartrate, 1 to 2 per cent. solution of grape sugar, $\frac{1}{2}$ to $\frac{1}{3}$ per cent. of sodium hyposulphite, 0·1 per cent. of potassium phosphate, and traces of calcium chloride.

We prepared some of this fluid and inoculated (sterilised) tubes of it with minute fragments of the following :—

1. *Ulva* which had fermented with sea water for 12 months in a stoppered bottle.

2. *Ulva* which had been fermented with tap water for the same time and under similar conditions.

Lead papers were suspended in the upper part of each tube by cotton-wool plugs, and the tubes then placed in the incubator. We also prepared a similar set of tubes containing $\frac{1}{3}$ per cent. of ferrous sulphate instead of the hyposulphite, and inoculated them in the same way. The first series we shall call A and the second B.

In 99 hours the lead papers in all the tubes were blackened except B 2, and a filmy growth was beginning to form on the surface of the liquid in two of the tubes. After a further interval of 24 hours, A 1 was covered with a pink growth, and A 2 with a white growth. A 1 was plated out in ordinary agar medium. but it gave no colonies, but A 2, similarly treated, gave plenty of well-defined colonies. Three of the latter were again plated out and inoculation from the resulting colonies made in tubes containing sterilised *ulva* and sea water, when after 5 days a whitish growth began to appear in the tubes, and two days later their contents were giving off sulphuretted hydrogen.

We have not had time to pursue the bacteriological investigation further, which very possibly in more experienced hands might have given more definite results, but we believe that the following conclusions are warranted from our experiments :—

(1) When the *Ulva latissima* ferments in water, it is attacked by a species of micro-organism, which is a spore-forming bacillus, and which probably infests the weed itself. The products of this fermentation consist mainly of propionic acid, but other fatty acids are formed in smaller quantities, together with carbonic anhydride and hydrogen. This micro-organism *probably* attacks the albuminoids of the seaweed.

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* Zelinsky, *Proceedings of the Russian Physical and Chemical Society,* 25, fasc. 5. [1893.]

(2) The fermenting *ulva* is attacked later by a second species of micro-organism, with the production eventually of ferrous sulphide and sulphuretted hydrogen. It seems probable that these sulphur compounds are produced from the sulphates of the sea water (or those contained in the tissues of the *ulva*), and not from the albuminoids of the seaweed, and that the micro-organisms are derived from the mud of the foreshore where the *ulva* grows.

Our experiments so far do not enable us to decide definitely whether the sulphuretted hydrogen is produced *directly* from the sulphates (or possibly the albuminoids), or *indirectly* from the ferrous sulphide, by the action of the organic acids. We are, however, of the opinion that some of the gas at least owes its origin to the second of these two causes.*

CERTAIN GREEN SEAWEEDS IN RELATION TO SEWAGE POLLUTION.

The evidence tending to prove that the occurrence of *Ulva latissima* in quantity in a given locality (and probably that of certain other green seaweed also, such as *Enteromorpha compressa*) is associated with the pollution of the sea water by sewage, is of four kinds, viz. (1) That afforded by the composition of the tissues of the seaweeds, or rather by the high proportion of nitrogen which they contain. (2) The avidity with which the seaweeds absorb inorganic compounds of nitrogen such as ammonia and nitrates from sea water. (3) An examination of certain localities in which the seaweeds occur in abundance, contrasted with others from which they are virtually absent. (4) Their spontaneous appearance and growth in certain sewage effluents at the experimental purification works in Belfast. Each of these pieces of evidence may be briefly reviewed.

1. The Proportion of Nitrogen in the Ulva Latissima and in Enteromorpha Compressa.

The most interesting and important results of our analyses of the tissues of these seaweeds—and certainly the most surprising to us—are first, the extraordinary proportion of nitrogen which they may contain, and second, the remarkable variations in this proportion depending apparently on the extent of the pollution of the water in which the seaweeds grew. In the following table the percentage of nitrogen in some other (dried) seaweeds is compared with that present in those just named, as well as the "proteine" (albuminoids) obtained by multiplying the percentage of nitrogen by the factor 6·25.

		Percentage of	
		Nitrogen.	Proteine.
	Ulva latissima from Contact Beds	8·94	55·875
	,, ,, ,, Belfast Lough	6·18	38·625
	Enteromorpha compressa from a Sewage Effluent	7·44	46·500
†	*Chondrus crispus* (Carragheen Moss)		
	Bleached, from Bewlay Evans	1·534	9·587
	,, second experiment	1·485	9·281
	Unbleached, from Ballycastle	2·142	13·387
	,, second experiment	2·510	15·687
	Gigartina mamillosa, from Ballycastle	2·198	13·737
	Laminaria digitata	1·588	9·925
	Rhodymenia palmata (Dulse)	3·465	21·656
	Porphyra laciniata	5·650	29·062
	Sarcophyllis edulis	3·088	19·300
	Alaria esculenta (Murlins)	2·424	15·150
‡	*Fucus saccharinus*	2·29	—
	,, *digitatus*	1·46	—
	,, *vesiculosus*	1·57	—
	,, *ceramium rubrus*	2·03	—

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* *See* p. 126.

† Thorpe's *Dict. Appl. Chem.*

‡ Würtz, *Dict. d. Chim.*

The farmers on the shores of Belfast Lough have discovered the value of the *ulva* as a manure, and large quantities are carted away by them and used on their land.*

Not only is the proportion of nitrogen in the samples of *ulva* and *E. compressa,* of which the analyses are given in the above table, extraordinarily high compared with that present in other seaweeds, but also with vegetables generally. Indeed in nitrogen content they resemble animal rather than vegetable products, as will be seen from the subjoined list of a few typical substances :—

Animal.	Percentage of Nitrogen, about :—
Meat (dry)	$10\frac{1}{2}$
Cheese (dry)	7
Milk (dry residue)	5
Vegetable.	
Peas	$4–4\frac{1}{2}$
Clover Hay	3
Wheat	$2\frac{1}{2}$
Meadow Hay	2

2. ASSIMILATION EXPERIMENTS.

Series 1.—Our first idea was to contrast the extent of growth of the *ulva* in pure sea water and in polluted sea water respectively ; and accordingly, as far as possible, similar tufts of the growing weed, adhering to stones, etc., and freshly removed from the sea-shore, were placed in two glass aquaria, one of which was filled with the pure sea water of the Irish Channel and the other with the same water to which $2\frac{1}{2}$ per cent. of Belfast sewage had been added. Photographs were then taken of the two tanks, with the object of contrasting them with photographs on the same scale to be taken later.

The result of this experiment was, however, curious, as the weed in both tanks soon became unhealthy and died in a month or two. We believe that the explanation was that in both cases the *ulva* was killed by the strong sunlight to which at times it was exposed, as the two aquaria containing it were placed in a window facing south-west, and the experiment was made in the spring-time.

Since then we have had a specimen of the seaweed growing for months in a glass dish placed near a window with a northern aspect, and as we write it is still in a perfectly healthy condition. It is a mere frond of the *ulva*, and was picked up on the shore, unattached to any support, and indeed, when we commenced our experiments with it, we were afraid that it would be of no use to us. But this frond has remained in perfect health for seven months, during which time it has been treated with several different specimens of foul sea water, and in the intervals has not been supplied with any pure sea water ; for after the failure of our first experiment it occurred to us that a far better method of investigation would be to examine the water in which the weed was growing, and not the weed itself.

The methods of water analysis are delicate, and by contrasting the composition of samples of sea water both before and after the *ulva* had been allowed to grow in them, it seemed to us that the information we desired ought to be readily obtained.

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* *Ulva latissima as a source of ammonia.*—The question naturally arises : Cannot the *ulva* be used for some practical purpose ? It is washed ashore in Belfast Lough (and some other places also) in enormous quantities, and in the former locality, only a very small fraction is carted away by the farmers for agricultural purposes. The rest, amounting in all probability to several thousand tons annually, either putrefies, and, as mentioned above, gives rise to a serious nuisance, or, in consequence of the prevailing westerly winds, gradually makes its way along the coast to the open sea. It seems a pity that such a valuable product is wasted, and the thought occurred that it might be utilised as a source of ammonia. It was easy to submit some of the *ulva* to destructive distillation and to ascertain the quantity of ammonia produced. Two experiments were accordingly made in which weighed quantities of the dried seaweed were distilled in glass tubes provided with an arrangement for catching the ammonia produced, and the amount of that substance was then determined. In the first experiment 100 parts of the dried *ulva* yielded 1·92 parts of ammonia, and in the second 1·82.

Now sulphate of ammonia is worth about £11 per ton, and it may be calculated from the above figures that 1 ton of that salt could be obtained from 14 tons of the dried seaweed, whereas *it requires 25 tons of coal to give the same quantity.* Hence it does not appear to be at all impossible that ammonia might be profitably manufactured from the *ulva* cast ashore in Belfast Lough.

The following experiments were, therefore, made :—

The frond of *ulva* employed was well washed for about an hour in running tap water to free it from debris. It was of large size, its area being 147 square inches, or about 1 square foot, and its active surface, therefore, twice that amount.

The dish in which it was placed was a circular glass vessel, with flat bottom and vertical sides, 8 inches in diameter and 3 inches high. It was provided with a cover similar to itself, and it contained in our experiments 1,600 c.c. of water. In order to get the frond of seaweed into the dish, it was folded across the middle.

Series 2.—*Assimilation of Ammonia.*—A sample of sea water was employed which was collected from a locality in Belfast Lough where several small sewers discharge directly into the sea, and was, therefore, presumably polluted. The frond of *ulva* was rinsed in the dish with some of this water, which was thrown away, and the dish then filled with more of the same water, the air-bubbles entangled in the folds of the seaweed being got rid of by gentle pressure with a glass rod. Some of the water was analysed before this was done, while after a week had elapsed a quantity of the water was removed from the dish and also analysed.

The results of the two analyses were as follows :—

	Parts per 100,000.	
	Free Ammonia.	Albuminoid Ammonia.
Original sea water - - - - - - - -	0·046	0·020
After contact with the *ulva* for 7 days - - - -	0·000	0·020

The seaweed had, therefore, absorbed *every trace of free ammonia* from the water, a result which was quite unexpected and highly interesting. On the other hand, none of the albuminoid matter had been absorbed, which, however, is quite in accordance with the known facts regarding plant nutrition. In order to verify this result, the *ulva* was allowed to remain in the same water for another week, when a second analysis was made with precisely the same results as before.

Series 3.—*Assimilation of Ammonia.*—This experiment was made with the view of getting some idea of the rapidity with which the *ulva* can absorb free ammonia from sea water, and also to ascertain whether it can thrive in a highly polluted water. The frond of *ulva* had remained in the sea water of the last experiment an additional four days, making eighteen days in all, and appeared to be quite healthy.

A sample of sea water was collected from the same locality as before, and to it 1 per cent. of sewage was added (obtained from the pumping station at the Belfast Main Drainage Outfall). This mixture gave, on analysis, the following results :—

	Parts per 100,000.	
	Free Ammonia.	Albuminoid Ammonia.
Sea water *plus* 1 per cent. sewage - - - - - - -	0·030	0·024

But as it contained less free ammonia than was expected, a standard solution of ammonium chloride was added, sufficient to bring up the free ammonia to 0·050 parts per 100,000.

The frond of *ulva* was drained from the first sample of sea water and rinsed with this mixture, again drained, and the dish then filled with the same mixture.

It was intended to make a series of analyses of the contents of the dish at intervals of about twenty-four hours, but to our astonishment we found that practically the whole of the free ammonia had been absorbed after a period of only seventeen hours, as the following determination shows :—

	In 100,000. Free Ammonia.
Sea water, *plus* sewage and ammonium chloride, after contact with the *ulva* for 17 hours - - - - - - - - - -	0·001

With the object of tracing the fate of the albuminoid matters, the weed was allowed to remain for about five weeks in contact with the mixture, while a flask containing the same mixture was also kept during the same interval. Both samples were then analysed, with the following results :—

	Parts per 100,000.	
	Free Ammonia.	Albuminoid Ammonia.
Sea water, *plus* sewage and ammonium chloride, kept for 5 weeks - - - - - - - - -	0·050	0·016
The same mixture after contact with the *ulva* for 5 weeks	0·004	0·017

These results further prove that the *ulva* cannot absorb albuminoid matters.

Series 4.—*Assimilation of Nitrates.*—The result of these experiments, as well as other considerations to be mentioned presently, induced us to extend our inquiry somewhat further, in order to ascertain whether the *ulva* can absorb nitrogen in the form of nitrates, with the same ease and rapidity as it assimilates that element as ammonia.

The same frond of *ulva* was again used, which had now been under observation in the dish for six months. In the interval from the last experiment, the water in which it was growing had been changed only once. On examination, it was found that, owing to the inflation of some of its under surface by evolved oxygen, a portion of the frond had become quite dry and almost bleached. We thought it highly probable that it was no longer in a sufficiently healthy condition for further experiment ; but having no other specimen at hand, we decided to test its vigour by its power of absorbing ammonia.

Some fresh sea water was therefore obtained and examined as follows :—200 c.c. were distilled until 100 c.c. had passed over, and 50 c.c. of this distillate were Nesslerised for the free ammonia. The residue left in the distilling flask was then diluted to the original volume (200 c.c.) with ammonia free water, and treated with zinc-copper couple for twenty-four hours at ordinary temperatures, then poured off, again distilled, and the distillate Nesslerised. The results of the analysis were as follows :—

	Parts per 100,000 Nitrogen, as :—	
	Free Ammonia.	Nitrates.
The sample of sea water contained - - - -	0·005	0·006

Sufficient ammonium chloride was added to this sea water to bring up the nitrogen as free ammonia to 0·042 parts per 100,000, and this strength was verified by a determination made as before.

The frond of *ulva* was now drained from the sea water in which it had been immersed for some months, rinsed with the new sample prepared as just described, and the dish then filled with the latter.

After twenty-four hours, 200 c.c. of the water were removed from the dish, distilled, and the distillate Nesslerised, when *no* free ammonia was found, proving that the seaweed was still in a perfectly vigorous condition. This was also shown by the copious evolution of oxygen which had occurred from it, the gas remaining entangled in the folds of the frond.

The water in the dish was next poured off, and sufficient of a standard solution of potassium nitrate added to it to bring up the nitric nitrogen to 0·05 parts per 100,000, when it was emptied back again. The frond of *ulva* was now in contact with ammonia-free sea water containing nitrates, and was allowed to remain thus for 70 hours, when a portion of the water was removed from the dish, and the nitrates determined by the same process as before. The water was found to contain 0·005 parts of nitric nitrogen, showing that the *ulva* had absorbed 90 per cent. of the amount originally present.

Series 5.—*Assimilation of Ammonia.*—Our next set of experiments showed that the *ulva* has far more energetic powers of ammonia assimilation than we suspected. The following are the particulars:—The seaweed employed was that already referred to as having been collected in Dublin, and sent in a sponge bag by post to Belfast, where accidentally it remained uncared for and unopened for a week (*see* p. 142 footnote). When examined several of the fronds were found to be in an incipient state of decomposition, but some appeared to be still healthy. The latter were well washed with tap water, trimmed with scissors to a convenient shape and the pieces placed in fresh sea water in glass dishes. The experiments on their power of ammonia absorption were made six or seven weeks after they had been collected (and after these experiments were terminated the seaweed remained in a perfectly healthy condition for more than a year).

Two different sets of experiments were made; the first with a solution of pure ammonium chloride in sea water, and the second with a mixture of sea water and the effluent from contact beds. All the experiments of the first set were made with the same piece of seaweed, and a similar remark applies to the second set in which, however, several pieces of seaweed were used. Individual experiments were made in both sets to test the absorptive power of the seaweed in relation to the concentration of the ammonia, as well as the effects of light and darkness. During each experiment the liquid remained at rest except just before the time when a sample was taken for analysis, when it was well stirred with a glass rod.

The following tables give the chief results obtained:—

ABSORPTION OF AMMONIA BY THE SEAWEED *ULVA LATISSIMA*.

(A) From a Solution of Ammonium Chloride in Sea Water.

Area of Seaweed Frond, 200 *square inches. Volume of Mixture,* 2½ *litres.*

Parts of Ammonia Originally Present per 100,000 of Liquid.	Percentage of Ammonia absorbed after					In
	1 Hour	2 Hours	3 Hours	4 Hours	5 Hours	
0·085	59	81	91	—	—	Daylight.
0·18	58	88	96	97	—	
0·085	37	77	87	91	—	Darkness.
0·96	29	44	56	67	73	

(B) From a Mixture of Contact Bed Effluent and Sea Water.

Area of Seaweed Fronds, 600 *square inches. Volume of Mixture,* 2½ *litres.*

Parts of Ammonia Originally Present per 100,000 of Liquid.	Percentage of Ammonia absorbed after					In
	1 Hour	2 Hours	3 Hours	4 Hours	5 Hours	
0·084	64	82	91	—	—	Daylight.
0·412	59	86	96	98	99	
0·080	18	45	58	—	—	Darkness.
0·095	58	79	87	94	96	
0·532	43	63	73	78	—	

The general conclusions which these results seemed to indicate were that:—

(1) The absorption of ammonia by the seaweed is very rapid, and with the mixtures used practically all was absorbed in five hours (except in one case).

(2) As a rule the amount absorbed is greatest during the first hour of contact, and then rapidly falls off.

(3) Although the concentration of the ammonia exercises some effect on the proportion absorbed, it is by no means so considerable as might have been expected.

(4) The seaweed absorbs ammonia both by daylight and in darkness, but the proportion absorbed in the latter case is apparently rather less than in the former.

(5) The effects of an increased area of the seaweed on the proportion, as well as the actual amount of ammonia absorbed, are not so great as might have been expected.

Series 6.—*Assimilation of Ammonia.*—Another series of experiments was made in order, if possible, to clear up various questions arising out of the preceding work, one of which was to find the limit of the *ulva's* absorbing powers.

A sample of fairly young *ulva* obtained from Belfast Lough was employed. The fronds were spread over the bottom of a large confectioners' jar and kept in position by weights consisting of short lengths of glass rod. This was done in order that the sea water containing the ammonium chloride might be kept in motion by a small automatic stirrer during the duration of each experiment. But the effect of thus pinning down the fronds would, no doubt, be to render their lower surfaces practically inoperative as regards absorption.

The following table contains the results obtained :—

ABSORPTION OF AMMONIA BY *ULVA LATISSIMA* FROM A SOLUTION OF AMMONIUM CHLORIDE IN SEA WATER.

Area of Seaweed Fronds, 90–100 *square inches.*

[Results stated as percentages of the Ammonia originally added which were absorbed after the given number of hours.]

Hours.	June 15th, 1904.	June 20th, 1904.	Sept. 6th, 1904.	Sept. 8th, 1904.	Sept. 9th, 1904.	Sept. 27th, 1904.	Sept. 28th, 1904.	Sept. 29th, 1904.
	0·25 per 100,000	0·119 per 100,000	0·1875 per 100,000	0·1875 per 100,000	0·1875 per 100,000	0·25 per 100,000	0·25 per 100,000	0·25 per 100,000
	Volume = 8 Litres.	Volume = 8 Litres.	Volume = 8 Litres.	Volume = 8 Litres.	Volume = 8 Litres.	Volume = 4 Litres.	Volume = 4 Litres.	Volume = 4 Litres.
	1	2	3	4	5	6	7	8
1	13·7	26·3	22·2	23·3	36·7	29·4	35·3	10·6
2	31·8	51·6	29·6	46·7	43·3	55·9	55·9	10·6
3	46	72·6	51·9	53·3	60·0	75·0	61·3	21·1
4	46	80·0	63·0	66·7	73·3	87·1	75·0	31·6
5	51·7	86·3	73·3	72·0	77·2	91·2	80·0	44·7
6	63·1	90·5	76·3	80·0	85·3	93·2	82·4	44·7
7	68·8	93·2	83·7	85·3	88·7	—	82·4	44·7
8	76·1	96·3	91·9	88·7	92·7	—	83·5	—
9	83·0	97·9	—	—	96·0	—	—	—

It will be seen that in no case was the absorption so rapid as that found in the 5th Series (Daylight), which is, no doubt, accounted for by a double cause, namely, a much larger volume of liquid and a much smaller area of seaweed.

Experiments 3, 4 and 5 were made under precisely the same conditions, and are interesting as showing a progressive activity in the absorptive powers of the *ulva.* Experiments 6, 7 and 8 were also made under the same conditions, but these were different from those obtaining in the three previous experiments, as the volume of liquid was 4 instead of 8 litres, and the concentration of the solution was increased from 0·1875 to 0·25 parts of ammonia per 100,000 of fluid. It will be seen that in experiment 7 the seaweed has maintained its activity during the first two hours, but afterwards this rapidly falls off, while in experiment 8 the falling off continues and the seaweed would appear, for the time being, at all events, to have almost lost its absorptive powers.

One of the questions which we were anxious to decide was the relative rates of absorption of nitrates and ammonia. Does the seaweed absorb the one as fast as the other, or is the rate different ? And, again, supposing that both ammonia and nitrates are present in sea water, will the *ulva* remove the two *pari passu,* or will it select one in preference to the other ?

Quite a number of experiments were made on this point during the preceding series on ammonia absorption, but the results are not given in the table, as the determinations of nitrate (by the zinc copper couple method) were most unsatisfactory, owing, as we subsequently discovered, to our having taken too much of the liquid for each determination. with the result, no doubt, that frequently the nitrate was not fully reduced, and as a consequence, only a part of that really present was found. Nevertheless, it is possible to draw certain conclusions, as, although *more* of the nitrate was probably present than shown by the different determinations, there could not have been *less*. Hence the quantities found may, at least, be regarded as minimal amounts.

Thus, in Experiment 2 the sea water contained both nitrate and ammonia, and as the table shows over 90 per cent. of the latter was absorbed at the end of the sixth hour. The quantity of nitrate at the commencement of the experiment was much the same as that of the ammonia, namely, 0·10 per 100,000 (nitric nitrogen as potassium nitrate), but the percentages remaining after the seventh, eighth and ninth hours, as found by analysis, were, respectively, 98·7, 85·7 and 85·7 per cent. of the original amount.

The slow rate of nitrate absorption by the seaweed contrasted with that of ammonia absorption was further shown by three series of experiments performed with the same seaweed in November, 1904—the nitric nitrogen added at the commencement of each being 0·25 parts per 100,000, and the volume of sea water 4 litres. At the end of the sixth hour the percentages of this amount found were 46·0, 78·2, and 82·4, and at the end of the eighth hour 56·9, 45·3 and 70·0.

Series 7.—Assimilation of Ammonia and Nitrates.—In August, 1905, additional experiments were made with the same seaweed, which was perfectly healthy in spite of its having been quite uncared for, except that the vessel containing it, and the sea water from the 1904 experiments was covered with a sheet of glass and protected from strong light by placing it on the sill of a window with a northern aspect. In these experiments the seaweed was not pinned down, nor was the mixture stirred except immediately before removing each sample for analysis.

As it was inconvenient to determine the nitrates at hourly intervals, a relatively large proportion of nitrate was added at first, and the determinations made at intervals of six, twelve or twenty-four hours. At first only 10 c.c. of the liquid was removed for analysis which were diluted with 200 c.c. of water, and the mixture treated for twenty-four hours with the zinc copper couple at 80° F. In this way the error of the previous experiments was avoided, namely, that of incomplete reduction of the nitrate to ammonia. In the first experiment it was intended to allow the seaweed to act simultaneously on both the nitrate and ammonia, and for that purpose at the end of seventy-two hours the liquid was poured off from the seaweed and 0·25 parts per 100,000 of ammonia (as ammonium chloride) added. Four litres of this mixture were then placed in contact with the seaweed, and the experiment continued. It will be seen, however, from the subjoined table of results that when the ammonia was added, practically all the nitrate had been absorbed.

ABSORPTION OF NITRATES AND AMMONIA BY *ULVA LATISSIMA.*

Area of Fronds, 90–100 *square inches.*

[Results stated as percentages of nitric nitrogen or ammonia originally added, which were absorbed after the given number of hours.]

Hours.	July 31st to August 4th, 1905. 1·00 Nitric Nitrogen per 100,000. Volume=5 litres ; Later, 4 litres.	August 3rd to 4th, 1905. 0·25 Ammonia per 100,000. Volume=4 litres.	August 30th, 1905. 1·153 Ammoniacal Nitrogen per 100,000.
6	15	—	50
12	15	—	64
24	39	—	86
30	53	—	—
36	61	—	—
48	75	—	—
60	85	—	—
72	Traces	100	—
96	0	0	—

Series 8.—*Absorption of ammonia by other green seaweeds.*—Had time and opportunity permitted, we should have liked to investigate the absorptive powers of all the chief varieties of green seaweeds as regards ammonia and nitrates. But we have only been able to perform a single series of experiments with one of these namely *Enteromorpha Intestinalis* in addition to our work already recorded on the *Ulva.*

This seaweed we are more inclined to regard as an indication of brackish as opposed to polluted waters, while for reasons to be mentioned later on *E. compressa* probably finds it *habitat* chiefly in the latter.

But having obtained specimens of the *E. intestinalis* at Belfast, which were of sufficient size to make a rough estimate of the total area of the fronds, (whereas with *E. compressa* this is nearly impossible) the experiment was made the results of which are recorded in the next table.

It will be seen that while this green seaweed absorbs ammonia, its " avidity " is not so strong as that of the *Ulva.*

ABSORPTION OF AMMONIA BY ENTEROMORPHA INTESTINALIS.

Area of Fronds probably about 50 *square inches.*

Volume of Mixture, 4 *litres.*

Hours.	0·25 Parts per 100,000. Percentage Absorbed.
1	9·1
2	18·2
3	29·0
4	37·5
5	46·0
6	51·7
7	57·4
8	57·4
9	60·2
10	63·0
11	63·0
22	74·5

* * * *

The absorption of ammonia by the *ulva* and other green seaweeds probably occurs according to a definite physical law, and possibly this law is similar to that governing the velocity of " monomolecular reactions " in chemistry, which finds its mathematical expression in the formula :—

$$\frac{-dC}{dt} = KC$$

If this law applied to the absorption of ammonia by the seaweed it would be stated thus :—

" The rate of absorption is constantly proportional to the concentration of the ammonia present."

From the above formula :—

$$\frac{-dC}{C} = Kdt$$

Therefore :—

$$\text{Log.}_e\, Co - \text{Log.}_e\, Ct = Kt$$

in which :—

Co = Percentage of ammonia originally present (100)
Ct = " " at time t
K = A constant

The mean figures for the experiments described in the tables p. 157, daylight series, as to the percentage of ammonia remaining after the action of the *ulva* are, in round numbers :—

Hours	0	1	2	3	4	5
Percentage of Ammonia remaining	100	40	18	6·5	2·5	0
Logs_e for percentage of Ammonia remaining	4·6052	3·6889	2·8904	1·8718	0·9163	0
Difference in Logs	—	0·9163	0·7985	1·0186	0·9555	0·9163

or K is, in round numbers, 0·9.*

Regarding the magnitude of the possible experimental errors and their effects on the value of K., it should be remarked that a relatively large error in the determination of ammonia at the commencement of the series would affect the differences between the logarithms much less than a far smaller error at its termination. Thus the difference between the logarithms of 40 and 30 is the same as that between the logarithms of 4 and 3, so that an error of 1 per cent. in the amount of ammonia towards the end of the determinations would affect the value of K as much as one of 10 per cent. near their commencement. The use of logarithms may, however, be avoided.

From the formula :—

$$\frac{-dC}{C} = Kdt$$

It may be shown that if t is equal to one hour

$$\frac{Co - Ct}{Ct} \text{ is a constant.}\dagger$$

Or in words: the amount of ammonia absorbed during each hour, divided by the amount of ammonia then remaining in the solution, is a constant.

In the following table we give the results of another series of experiments in which the value of the constant, deduced from the ammonia absorbed by the *ulva* during the first hour, has been employed to calculate the ammonia which ought theoretically to have remained (unabsorbed) in the solution at the end of each succeeding hour, due allowance being made for the ammonia removed in the quantity of solution taken for each analysis.

In another column these results are compared with the ammonia found by experiment; while, in a third, the percentage differences between the two sets of figures are given.

Volume of Ammoniacal Sea Water originally taken, 8 *litres. Area of Ulva Fronds,* 90–100 *square inches. Ammonia present in the Sea Water at the Commencement of the Experiments,* 0·015 *grammes.*

Constant = 0·233.

Ammonia remaining Unabsorbed.			Percentage Difference between Calculated Amount of Ammonia (100) and the Amount found by Experiment.
At End of Hour.	Found by Experiment.	Calculated from Constant $\frac{Co-Ct}{Ct}$.	
2nd	0·0076000	0·0083800	— 9·3
3rd	0·0064750	0 0062580	+ 3·5
4th	0·0045000	0·0046703	— 3·7
5th	0·0036750	0·0034827	+ 5·5
6th	0·0025500	0·0025945	— 1·7
7th	0·0018150	0·0019310	— 6·0
8th	0·0013600	0·0014370	— 5·4

---

* If at the end of the second hour the percentage of NH_3 found had been 16, the differences in logs. would be :—0·9163, 0·9163, 0·9008, 0·9555, 0·9163.

† Thus :—

$$\frac{-dC}{C} = Kdt$$

$$\text{Log. } \frac{Co}{Ct} = Kt \text{ and if } t = 1 \text{ hour Log. } \frac{Co}{Ct} = K$$

$$\frac{Co}{Ct} = e^k \text{ and } \frac{Co - Ct}{Ct} = e^k - 1 = \text{a constant.}$$

As to the magnitude of the experimental error in this series, and their effects on the calculation, it may, we think, be assumed that a trained observer can estimate, by Nesslerising the amount of ammonia present in 50 c.c. of a not too strong solution, to within 0·0025 mgs., *i.e.*, that with the weak solution of ammonium chloride generally employed for the purpose (1 c.c.=0·01 mgs. NH_3), he can detect a distinct difference in tint between, say, 3 c.c. of this solution in 50 c.c. of (ammonia free) water *plus* the Nessler re-agent and $3\frac{1}{4}$ c.c. when similarly treated. Allowing, therefore, as a possible experimental error in the several determinations, the above mentioned amount: then with the quantity of ammoniacal sea water first removed from the 8 litres in the above series and distilled (200 c.c.), and the fraction of the distillate (10 c.c. out of 100 c.c.) Nesslerised, the experimental error would amount to :—

$$0{\cdot}0025 \times \frac{10}{2} \times 80 = 1 \text{ mg.}$$

—corresponding with about 7 per cent. of the total ammonia originally present in the solution (15 mgs.).

At the end of eight hours, 50 c.c. out of the 100 c.c. of the distillate (from 200 c.c.) of the sea-water were Nesslerised, while 1,600 c.c. of the original liquid had been removed for the several analyses leaving 6,400 c.c. The experimental error may as a consequence now amount to :—

$$0{\cdot}0025 \times \frac{2}{2} \times 64 = 0{\cdot}16 \text{ mg.}$$

—corresponding with about 11 per cent. of the total ammonia remaining in the solution (say, 1·4 mgs.).

An inspection of the table given above will show that the differences between the observed and calculated results exceeds the limit of the experimental errors in one case only, and then only slightly.

The actual value of K, while constant for a given set of conditions, would no doubt depend upon a number of factors, such as the area of the seaweed fronds, the concentration of the ammonia in the sea water, the volume of liquid, etc. Thus, in the first set of results quoted above, the area of the seaweed was large and the volume of liquid small, whereas, in the second, the area was much less while the volume of liquid was much larger. It will be found that if the value of K is calculated in the same way in both series it is rather more than four times higher in the first than in the second.

3. CERTAIN LOCALITIES IN WHICH THE ULVA OCCURS IN ABUNDANCE CONTRASTED WITH OTHERS FROM WHICH IT IS VIRTUALLY ABSENT.

It may be stated broadly that no localities have as yet come under observation where the *ulva* occurs in abundance in which the water is *not* polluted with sewage.

But, on the other hand, the seaweed is not always to be found in abundance in all places where the sea water *is* polluted. It is probable that certain other conditions are necessary for its growth, which have not as yet been determined with certainty, but of which a sluggish flow of water, as opposed to a strong tide, and a suitable bed are possibly the most important.

Attention may, however, be drawn to two particular localities where the seaweed is abundant—viz., Belfast and Dublin, with which we are specially familiar—and one from which it is virtually absent—viz., Strangford Lough.

The condition of Belfast Lough will be described in detail in a special section, but it may be mentioned here that with the growth of the City of Belfast and also with the removal of the sewage outfall from the river Lagan to well out into the Lough, the quantity of *ulva* growing in the latter has increased largely. Moreover, in Belfast Lough the tides are sluggish—at all events in its upper reaches—and from the investigation of its waters, there can be no doubt that a portion of the sewage, and probably a considerable one, does not make its way out of the Lough on the ebb tide, but having drifted a certain distance towards the open sea, is washed backwards by the flood tide which probably distributes it over a fairly large area, thus keeping the upper reaches in a constantly polluted condition.

Strangford Lough, which is quite close to Belfast Lough, resembles the latter in extent of area, in the large banks of sand or mud exposed at low water, and also in the fact that the tides are sluggish in the upper reaches. It differs from it, however, in that no large town is situated on its shores. In this Lough, however, *ulva latissima* does not occur in any quantity.

In Dublin Bay the conditions under which *Ulva latissima* occurs in quantity are both interesting and significant.

Broadly speaking, the upper reaches of the Bay are divided artificially into two portions by the so-called Pigeon House wall, which extends for more than a mile and a half in an easterly direction, and terminates in Poolbeg lighthouse. A second wall, called the North Bull wall, juts out from the northern shore of the Bay at Dollymount, and extends in a south-east direction to within about 1,000 feet of Pool Beg lighthouse, terminating in a second lighthouse called the Bull. The northern part of the Bay thus almost enclosed by the two walls forms the harbour. On the other hand, the southern portion of the Bay is quite open (*see* Map facing p. 271).

The harbour receives not only the waters of the Liffey River into which the major portion of the city sewage at present flows, but also those of the Tolka River, which is polluted by a large sewer running into it close to its mouth, while another large sewer discharges directly on to the northern shore close to the city, as well as a considerable number of smaller sewers the whole way thence to Dollymount.*

On the other hand, no sewers of any magnitude (if indeed any at all ?) discharge their contents into the southern portion of the Bay until Blackrock and Kingstown are reached, which are quite at its mouth. Thus, broadly speaking, the northern portion of Dublin Bay consists of a polluted area, while the southern portion is unpolluted. Now, plenty of the *ulva* is found on the northern shores of the harbour, and is washed up along the Clontarf foreshore, where, as in Belfast Lough, it rapidly putrefies in warm weather, and gives rise to a nuisance. On the other hand, the southern portions of the Bay seem to be quite clear of the seaweed until Blackrock and Kingstown are reached, where it is found in fair quantity.

4. THE SPONTANEOUS APPEARANCE AND GROWTH OF THE ULVA AND SOME OTHER GREEN SEAWEED IN SEWAGE EFFLUENTS.

Perhaps the strongest piece of evidence in support of the view that the growth of certain green seaweeds is associated with sewage pollution is that afforded by their recent appearance and development during the purifying processes to which a certain portion of the Belfast sewage is submitted at the experimental works.

In the autumn of 1902 patches of a green growth made their appearance on some of the lower contact beds filled with brick fragments, and this growth had the appearance of one of the varieties of green seaweed at an early stage of development. By the spring of 1903 these growths had developed into large patches of *Ulva latissima* distributed over the surface of the beds, but especially abundant at their margins.

The fronds were quite healthy and of considerable size, being in many cases four or five inches in diameter, and several barrow loads could have been removed from the beds, so abundant was the seaweed. Probably the growth would have been even more vigorous but for the persistent attacks of earth worms, which were found in it in large numbers.

In the winter of the same year the patches of seaweed dwindled in size, but did not disappear entirely, and again in the following spring (1904) vigorous growth was observed, but some, at least, of the seaweed was now found to consist of a species of *enteromorpha*,†

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* Since this was written a new main drainage scheme for Dublin and the northern portion of Dublin Bay has been inaugurated (*see* p. 301).

† The growth has continued this year (1905), and for the first time the seaweed then appeared in the upper contact beds.

It may be mentioned that the beds in question were employed for the treatment (second contact) of screened and settled sewage without intervention of the septic tank.

In another part of the experimental station a small (closed) septic tank had been constructed, together with a pair of small contact beds (one upper and one lower) also filled with brick fragments. The screened and settled sewage after being treated by this installation flowed into a pond from which it was occasionally pumped.

In the spring of 1902 green vegetation also appeared in this pond and increased so rapidly that in a few months the pond was practically full of it, and on a botanical examination it was found to consist of the green seaweed *Enteromorpha compressa.* Later in the year, however, another species of *enteromorpha* appeared, viz., *E. intestinalis* and also the *ulva.*

How did these seaweeds originate ? It was not possible for sea water or seaweeds to gain admission directly either into the contact beds or into the pond in which the *enteromorpha* was found.

But on the other hand leakage of water from the tidal river Lagan into the low level sewer (which runs beside it) was not only possible but was known to occur. Moreover, a portion (and probably a not inconsiderable one) of the river water is introduced into the sewer by manufacturers who use it for condensing and other purposes.

Thus the only probable explanation of the occurrence of the seaweeds in the sewage effluents is that their spores were carried by the tide up the river and thence passed into the main drainage system.

That seaweeds of any kind should make their appearance and grow freely in a sewage effluent is very singular, but Belfast sewage contains as a rule abundance of chlorides—no doubt introduced as sea water in the manner just mentioned—not infrequently amounting to more than 100 parts per 100,000 (0·1 per cent.), though at other times it sinks to nearly the normal amount. It is evident, therefore, that green seaweeds have remarkable powers of adapting themselves to what would appear to be a very unfavourable environment, and that they can thrive in water which frequently changes its degree of salinity through wide ranges.

THE FUNCTIONS OF GREEN SEAWEEDS IN NATURE.

From what has been stated regarding the occurrence of the *ulva,* and the remarkable powers of assimilating nitrogenous compounds such as ammonia and nitrates which that seaweed possesses, it seems highly probable that it may be regarded as an instrument which nature has designed for the final purification of polluted sea water.

After bacterial action is over and the nitrogen of the albuminoids and other organic compounds originally present in the polluting matters has been converted into ammonia or nitrates, the *ulva* comes into play and rapidly absorbs these substances.

But this is not its only function. for in common with all green vegetation carbonic anhydride is necessary for its existence, and this it finds supplied to it in abundance by those processes of resolution which the micro-organisms have already effected in the organic constituents, both nitrogenous and non-nitrogenous, of the polluting matters.

And here attention may be drawn to a somewhat important difference between terrestrial and aquatic plants in relation to the gaseous exchanges which occur between them and the fluid media which surround them.

In the case of land plants growing in manured soil, the carbonic anhydride evolved from the latter passes into the air where it rapidly diffuses, and unless confined (as in a gardener's " frame ") is quickly removed from the sphere of plant action.

But in the case of aquatic plants growing in a sewage polluted water, the escaping carbonic anhydride is retained in solution, and consequently, if not swept away too rapidly by currents, is immediately available for absorption by the plants.

The absorption of carbonic anhydride by any green plant is attended later by a corresponding evolution of oxygen, and here again there is a difference between land plants and water plants in their relations to this gas and their surroundings, of precisely the same kind as that just mentioned for carbonic anhydride, namely, that in the case of aquatic plants the escaping oxygen is retained in solution and hence is available for " self purifying " purposes by the water.

It is quite possible indeed to obtain a jar of oxygen gas from sewage itself, the oxygen coming eventually from the organic compounds originally present in the sewage. It is only necessary to expose a bottle filled with sewage (or better, with a sewage effluent) to light, when after a time green growths make their appearance, and soon a rapid evolution of gas takes place which, if collected, is found to be almost pure oxygen.*

Here the course of events is, no doubt, as follows. The first attack of the micro-organisms results in what has been termed the " carbon fermentation," that is to say the chief chemical change which occurs consists in the liberation of carbonic anhydride from the organic compounds. The spores of the green growths are present in the original sewage, and germinate when the conditions become favourable. The resulting green growths next act on the carbonic anhydride and convert it into oxygen, absorbing carbon from it, and also nitrogen from the ammonia produced during the putrefaction of the organic matter.

The importance of aquatic vegetation in supplying dissolved oxygen to a given water and more especially to a polluted water cannot be over-estimated, both as regards the self-purifying processes occuring and also in relation to the lives of aquatic animals.

The *ulva* is not only characterised by its ability to absorb ammonia and nitrates, but also (and no doubt as a result of this action) by the large volumes of oxygen which it gives off. The stimulating effects produced by adding either salts of ammonia or quantities of a sewage effluent to the sea water in which fronds of the *ulva* are growing were frequently noticed in the experiments previously described—leading to a rapid evolution of gas from the surface of the seaweed, which occasionally amounted to a veritable effervescence.

Two special experiments were made in which the dissolved gases contained in a sample of sea water were extracted (by boiling out *in vacuo* with sulphuric acid)—both immediately after adding the polluting material, and again some hours later—and were then analysed. The following results were obtained :—

EXPERIMENT 1. (DAYLIGHT).

Gases found in cubic centimetres per litre in the water at N.T.P. :—

Immediately after adding Ammonium Chloride Equivalent to 0·180 parts of ammonia per 100,000.		Four Hours Later.
Carbonic Anhydride	21·69	15·90
Oxygen	11·41	14·84
Nitrogen	9·79	9·88

Loss of dissolved carbonic anhydride - - - - - - 5·79
Gain on dissolved oxygen - - - - - - - - - 3·43

[About 2 cubic centimetres of evolved oxygen gas were collected in addition.]

EXPERIMENT 2 (DARKNESS).

Immediately after adding 20% of a Sewage Effluent		Four Hours Later.
Carbonic Anhydride	63·59	66·44
Oxygen	6·31	3·85
Nitrogen	11·90	11·74

Gain on dissolved carbonic anhydride - - - - - - 2·85
Loss on dissolved oxygen - - - - - - - - - 2·46

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* In an experiment thus conducted with a flask containing about ¾ litre of a sewage effluent more than 20 cubic centimetres of oxygen have been collected in twelve hours.

The above analyses are interesting in several ways. Thus in the first experiment the amount of dissolved oxygen found is greatly in excess of that given by Dittmar in the "Challenger" reports for the volume of oxygen which one litre of sea water can take up from air. The action of the *ulva* was, therefore, in a sense to *super-saturate* the sea water with oxygen.

Secondly, the amount of carbonic anhydride found in the same experiment is much less than that present in normal sea water, Dittmar's average amounting to about 48 cubic centimetres per litre, of which, in all probability some 40 cubic centimetres are in the form of soluble bicarbonates of calcium and magnesium. It is evident, therefore, that the *ulva* had gained its carbon chiefly from the carbonic anhydride of these salts.

Thirdly, the results of the experiment in darkness demonstrate in an interesting manner the true respiration of the *ulva*, carbonic anhydride being evolved in practically the same amount as that of the oxygen disappearing.

It is a well known fact that a few fronds of growing *ulva* keep a marine aquarium healthy. In the light afforded by the experiments described, the reason for this seems clear.

Not only is it an admirable scavenger, but it also provides an abundant supply of oxygen, while at the same time removing the dissolved carbonic anhydride. Not only is the dissolved oxygen of importance to the lives of the marine animals, but it also prevents, or at least, retards putrefactive changes.

Although direct experiments have not as yet been made with other species of green seaweeds, it can scarcely be doubted that their functions are of a similar character to those of the *ulva*.

The suggestion may indeed be made that seaweeds generally form a kind of mechanism, whereby the nitrogenous substances washed out of the soil and constantly passing down rivers into the sea are retained and prevented from escaping into the ocean.

That the *ulva* should at times cause a nuisance by its excessive growth and subsequent decay, is, it need scarcely be said a mere accident, and may indeed be regarded as an example of the difficulties attending the disposal of organic refuse in a thickly populated district.

Could the growths of the *ulva* which are cast ashore in Belfast Lough in thousands of tons annually be transported without cost, or even at a trifling cost, to the outlying agricultural districts, no nuisance would ever occur in the Lough itself, as the farmers would be only too eager to remove the seaweed. But the local supply exceeds the local demand, and as yet no simple and economic method has been discovered for converting the seaweed into a manure or other commercial product of sufficient value to meet the cost of collection, and these remarks also apply to other localities where the seaweed occurs in quantity.

MISCELLANEOUS NOTES ON GREEN SEAWEEDS.

(1) *Ulva latissima* appears to be a seaweed of the annual class. It dies down in the winter to reappear in spring and summer. But like other annual plants it may survive during a mild winter under natural circumstances,* and observations made in Belfast show that it often does so. On the other hand during a hard winter it completely disappears, at least on the large scale; and the change in the appearance of the banks exposed at low water from green to yellow (viewed at a distance) is quite striking. But even in fairly early spring after a hard winter, large fronds of *ulva* appear which can scarcely be the product of a few months' growth. Have these fronds lain in the deeper water during the winter, and been floated up by the bubbles of disengaged oxygen as the sun regains its power?

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* When kept in an aquarium and not exposed to frost it lives for an indefinite time.

(2) *Functions of aquatic vegetation.*—Our studies on these green seaweeds seem to open up a wide field of research as to the functions of aquatic plants in general, which we think would be well worth attention. Every plant and no doubt every organism has its proper place and functions in nature, and the occurrence of a particular species in a given locality no doubt has its own special significance. Anyone who has carefully examined the appearance of a stream into which sewage is discharged, on the one hand near the outfall and on the other lower down, must have been struck with the changes to be noticed in the character of the vegetation. The sickly looking grey or brown filamentous growths which are to be found adhering to the stones, etc., near the point of discharge, gradually give place as the stream is descended to green vegetation of various kinds, and the appearance both of the stream and water would be described in ordinary language as "clean looking." Can it be doubted that each of these different forms of vegetation exercises its own specific functions on the water and prepares it for those of its neighbours further down ?

Similar remarks no doubt apply to the different growths which appear in sewage itself during the different stages of its purification by the processes now employed. "Every liquid of greater or less impurity passing through the channels, seems to register its condition on the walls of the channel ; in some cases grey growths, in other cases green growths, in other cases you are liable to get more organised plants."*

It would, we suggest, be of considerable interest to investigate the chemical changes induced in a polluted water by at all events the chief types of these different forms of vegetation.

(3) *An aquatic sewage farm.*—The preceding remarks suggest that possibly sewage might be satisfactorily treated by what might be termed an "aquatic sewage farm," that is to say that it might be passed through a series of tanks each containing a predominance of those forms of vegetation suitable to effect the successive changes leading to its final resolution into inorganic compounds which would be absorbed by the vegetation and a well oxygenated effluent result. One of us has suggested this idea in connection with the *ulva* nuisance at Belfast, the proposal being to submit the effluent from the ordinary purification processes to a final treatment in a tank or lagoon containing plenty of the *ulva* to remove nitrates and any ammonia remaining, and so to prevent the growth of the seaweed in the Lough itself where it is so difficult to collect, by thus cutting off its sources of nourishment.

(4.) *The amount of ulva which may be produced from the sewage of a given locality.*—The following calculation may be of interest as showing the possible extent of an *ulva* nuisance due to the sewage of a given locality. Take the case of Belfast, for example, with a population of some 350,000, and suppose (1) that the *ulva* derives its nitrogen from the ammonia present in the sewage ; (2) and, further, that all this ammonia is absorbed by the seaweed, and passes into its tissues ; also (3) that the *ulva* as collected, contains 90 per cent. of moisture. Then as the *ulva* from Belfast Lough contains 6 per cent. of nitrogen, and Belfast sewage 2 parts per 100,000 of nitrogen as ammonia—both in round numbers—one gallon of sewage can originate

$$\frac{2 \times 70{,}000}{100{,}000} \times \frac{100}{6}$$

or in round numbers, 23 grains of dry seaweed, and one pound of dry seaweed will be produced from

$$\frac{7{,}000}{23}$$

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* Part of a question asked one of us by Col. Harding. *See* Fifth Report of Royal Commission on Sewage Disposal. Vol. II. (Q. 24858.)

or *about* 300 gallons, and one pound of *wet* seaweed from about 30 gallons, *i.e.*, the daily sewage of one individual. Consequently, in one year the total production of wet seaweed from the population of Belfast would amount to

$$\frac{365 \times 350{,}000}{112 \times 20}$$

or about 57,000 tons.

There are, of course, obvious fallacies in the assumptions made in the above calculations, of which the chief are—(1) that all the ammonia in the sewage passes into the seaweed, and (2) that the production of seaweed occurs all the year round; but as a set off to these, no account is taken of the ammonia gradually evolved from the sewage sludge which has accumulated for years in Belfast Lough, and which actual experiment has shown to be constantly giving off that substance. Also it can scarcely be doubted that the putrefying *ulva* itself gives off ammonia, although no direct experiment has been made on this point.

(5.) *Ulva latissima in foreign waters.*—The occurrence of this seaweed in polluted localities is not confined to British waters. Mr. Thomas Thornton, at that time travelling Inspector of Cotton Growing, writing to one of us from Barbados in 1904 stated that he had found it in abundance there in the neighbourhood of a sewage outfall, but had not seen it elsewhere in the island.

During a recent visit to the town of Lerici in Italy, one of us found the same seaweed in abundance in the harbour which is extensively polluted with sewage, but not (in appreciable quantities) along the neighbouring coast where sewers were absent.

(6.) *Disappearance of ulva when pollution ceases.*—Surgeon-Colonel Flynn of the Local Government Board (Ireland) has informed one of us that formerly the southern shore in the upper reaches of Dublin Bay was polluted by sewage and that *ulva* was then found there in quantities. Since this sewage has been intercepted and taken to Kingstown the growth of *ulva* has been transferred to that place near the outfall and in the harbour.

E. A. L.

SECTION 4.

ON THE EFFECTS INDUCED BY DIFFERENT METHODS OF SEWAGE PURIFICATION.

ON THE EFFECTS INDUCED BY DIFFERENT METHODS OF SEWAGE PURIFICATION.

It may be suggested that the type of purification process for a given locality might often vary with advantage according to the conditions there prevailing and the nature of the interests mainly involved.

In preparing an effluent for discharge into a non-drinking water stream (the only case which need here be considered) it seems to us that it is important to distinguish between the following cases :—

(1) Effluents passing into a non-fishery stream.
(2) The same passing into a fishery stream.
(3) The same passing into an estuary or tidal locality where a nuisance arising from the growth and subsequent decay of green seaweeds is to be avoided.

The first of these cases is of special importance in relation to certain manufacturing districts, such as those in the watersheds of some of the Lancashire and Yorkshire rivers, where the population is dense, the manufacturing interests of prime importance, and the rivers small. In many of these places the rivers consist mainly of sewage and manufacturing effluents, and fish life is impossible.

Under these circumstances the main object to be kept in view is the prevention of a nuisance, and in all probability that is best accomplished as regards sewage treatment by first separating the solids as completely as can be done, and then obtaining as highly nitrated an effluent as possible.

In cases of this kind the amount of dissolved oxygen in the effluent as it leaves the purifying station is not a factor of prime importance, provided that nitrates are present in sufficient quantity to prevent eventual putrescence.*

But in the second class of case the requirements are different, the presence of nitrates not being essential, while on the other hand dissolved oxygen is *the* important factor.

Hence an effluent which is discharged into a fishery stream ought, in addition to being free from suspended solids, and devoid of substances toxic to fish, to be sufficiently aerated.

In the third class of case, that is to say the avoidance of an *ulva* nuisance at a seaside locality, or the growth of excessive vegetation in rivers, the main object to be aimed at should be the removal from the sewage or effluent of those substances which encourage the growth of aquatic plants, namely ammonia and nitrates.

As one of us has been engaged for several years past in an experimental study of the latter question, and as the results of the investigation bear generally on the subject of the effects of different methods of sewage treatment on the nature of the resulting effluent, some account of the work may be useful, especially as the sewage dealt with was in all cases from the same source, so that the results obtained are comparable with each other in the different series.

1. *Effects of treating screened and settled Sewage by Double Contact Beds.*

The experimental plant to test the effects of this method of treatment consisted of four beds—two upper and two lower—each bed being about 90 feet long and 72 feet wide, and with an average depth of 3 feet.

The filling material used in three of these beds (one upper and two lower) consisted of broken bricks, and in the remaining bed of coke. The material in all the beds was of the same size, namely, about 2½ inches in diameter. It should also be stated that when the experiments were commenced the beds had been working practically continuously for two years.

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* See Appendix 1 of this Section.

The sewage was that of the city of Belfast, most of which by the method of disposal then employed after rough screening passed into a large underground tank, where it was stored previous to discharge into the Lough on the ebb tide. In the experiments in question the time occupied in each working cycle of the experimental contact beds was as follows:—

Filling upper beds	¾ hours
Resting full (upper beds)	2½ ,,
Emptying upper and filling lower beds	¾ ,,
Resting full (lower beds)	2½ ,,

Systematic analyses were made of the screened and settled sewage and of the effluents from first and second contact with the beds during a period of six months, and under different conditions of weather, time and season, in order to obtain information as to the average effect of the purifying process.

These analyses are given in detail on pages 46 and 47. Here it will be sufficient to mention the chief results obtained.

Regarding the free or saline ammonia, it was found as the mean of all the determinations that 27½ per cent. was lost after single contact, and 51½ per cent. after double contact, while the corresponding figures for the albuminoid ammonia were, in round numbers, 41½ and 71 respectively.

Virtually no nitrates or nitrites were found in the effluent, but on the contrary, the small quantity of nitrate present in the original sewage (average 0·14 parts of nitric nitrogen per 100,000) almost entirely disappeared (average in the effluent 0·03 parts of nitric nitrogen per 100,000). The question therefore arose as to what had become of both the ammoniacal and albuminoid nitrogen which had disappeared from the sewage during the purification process, and it was suggested that this disappearance could occur in two ways only, namely, (1) that the missing nitrogen had been converted into free nitrogen which had escaped in the gaseous state, or (2) that nitrogenous compounds might have passed into the tissues of animals or vegetables present in the contact beds. That the first of these explanations regarding part, at least, of the lost nitrogen was true, was definitely proved by the analyses of the dissolved gases in the sewage and effluents.

Thus in all of the latter (from second contact) with one exception more free nitrogen was found than in the corresponding sample of the former. But as the first six series of analyses only were made under exactly the same conditions, a detailed examination of the results may be confined to them. In these the excess of free nitrogen in the effluent from second contact (over that present in the sewage) amounted in weight to 0·272 parts per 100,000, while the loss of unoxidized nitrogen (Kjeldahl) which had occurred in the sewage amounted to 2·2 parts, and therefore rather more than 12 per cent. of the nitrogen lost was thus accounted for, while in one particular sample it amounted to nearly 20 per cent.

It may, we think, be safely assumed that this excess of free nitrogen found in the effluent represented only a fraction of that actually produced, the remainder escaping in the gaseous condition.

As regards the possibility that nitrogen is lost biologically, that is to say, that its compounds pass into the tissues of animals or plants which inhabit the contact beds, it is certain that a portion does escape in that way. Contact beds teem with living organisms in addition to bacteria, and a systematic examination of the different species present would be of great interest and value. In the beds employed in the experiments described above, and in similar beds which we have seen elsewhere, a small insect, *Podura aquatica*, was present in large numbers. Escaping in myriads from the beds, they often formed quite a thick layer on the surface of the pond into which the effluent passed, which from a distance looked like soot. There can be no doubt that these animals feed on the sewage and that in escaping they carry with them some of its nitrogenous constituents.

Earthworms are also abundant in certain contact beds.*

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* In the spring of 1907 large numbers of small worms were found in a tank at the Belfast Experimental Works into which the effluent from a sprinkling filter passed. These were submitted to Mr. R. Southern, of the Dublin Museum, for identification, who reported as follows:—

"The species is *Lumbricillus* (*Pachydrilus*) *subterraneus* (Vegdovsky). It is described in the *Revue Biologique du Nord de la France*, 1889, p. 121. It is most interesting to find that the only other localities for this worm are the subterranean waters of Pragu and Lille, where Vegdovsky found it."

Regarding vegetable life, as elsewhere stated in this Report (pp. 163-4), a species of *Enteromorpha* appeared spontaneously on the surface of the contact beds at Belfast some years ago and is now growing luxuriantly, and to such an extent in the summer months that the surface of the beds appear quite green. The functions of this seaweed in relation to sewage are discussed elsewhere in this Report (p. 164).

2. *Effects of treating Sewage in a Septic Tank and afterwards by Double Contact Beds.*

A systematic series of experiments was conducted on this method of sewage treatment, in consequence of the observation that a much higher degree of purification appeared to have been obtained in those places where this method was adopted than in others where the sewage was submitted to contact bed treatment only. Thus at Manchester, where an experimental septic tank and contact beds had been installed some time before our own experiments, the purification amounted to 84 per cent. in the free ammonia and 82 per cent. in the albuminoid ammonia, whereas both at Leeds and Belfast, where the sewage was submitted to contact bed treatment only, the results were similar and amounted to a loss in free ammonia of a little over 50 per cent. and albumenoid ammonia to rather more than 70 per cent.

The plant employed in our experiments consisted of a small closed septic tank in conjunction with two new sets of contact beds.

The septic tank was not specially made for the purpose, but formed part of a disused brick culvert. It had a capacity of about 4,700 gallons and was filled by gravitation with screened and settled sewage from the large underground storage reservoir already mentioned.

The contact beds were each 19 ft. long, 11 ft. wide, and 2½ ft. deep. The upper series contained fragments of broken bricks which passed through a 1½ in. mesh but were rejected by a ½ in. mesh, while the lower series contained fragments of the same material but of finer grade, namely, such as passed through a ½ in. mesh but were rejected by an ⅛ in. mesh.

The working cycle of this installation was as follows:—

Resting in septic tank - - - - - -	12 hours
„ „ upper contact bed - - - -	3 „
„ „ lower „ „ - - - -	3 „

In all 9 complete series of analyses were made with this installation, the samples being collected on such days and at such times as would as far as possible give when the mean of the analyses was taken a fair idea of the average composition of the original sewage and of the purification effected.

In another series of experiments on this method of treatment a new septic tank was was used, now an open one, but the same contact beds were employed as in the previous series. The working cycle in this series was as follows:—

Resting in septic tank - - - - - -	19 hours*
„ „ upper contact beds - - - -	3 „
„ „ lower „ „ - - - -	3 „

The analytical results obtained in this latter series of experiments are collected in the following table:—

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* Previous to reaching the septic tank the sewage was kept in an underground storage tank for a period varying from 1 to 5 hours.

EFFECTS OF SEPTIC TANK AND DOUBLE CONTACT (B).

Series.	Sample.	Rainfall.	Date.	Time of Collection of Samples.	Temperature of		Parts per 100,000.									Dissolved Gases. Cubic Centimetres per Litre at N.T.P.				
							Solids in Suspension.			Chlorine.	Oxygen Absorbed 4 hrs. at 80°F.	Nitrogen as								
					Sample.	Air.	Volatile.	Fixed.	Total.			Free Ammonia.	Albd. Ammonia.	Nitrite.	Nitrate.	Carbonic Anhydride.	Oxygen.	Marsh Gas.	Hydrogen.	Nitrogen.
			1903.		°F.	°F.														
1	Crude Sewage	0·065*	Dec. 15	3.30 p.m.	40	44·5	—	—	40·92	34·0	5·22	1·48	1·18	0	0·08	—	—	—	—	—
	Screened and Settled Sewage...	—	" "	7.30 "	48	44	—	—	—	38·0	4·05	1·48	0·49	0	0·00	101·79	0	1·24 ?	?	16·44
	Septic Tank Effluent	—	" 16	1. 0 a.m.	48	43	—	—	9·76	32·8	3·79	1·48	0·58	0	—	99·81	0	1·47	0	17·01
	Lower Contact Bed Effluent ...	—	" "	7. 0 "	46	41	—	—	1·20	—	1·09	0·23	0·16	0	0·37	88·69	1·45	0	0	18·04
			1904.																	
2	Crude Sewage	0·220*	Jan. 12	3.30 p.m.	48	45	21·4	9·0	30·40	47·8	11·01	1·98	1·48	0	0·16	—	—	—	—	—
	Screened and Settled Sewage ...	—	" "	7.30 "	46	43	—	—	—	40·5	10·78	1·98	1·23	0	0·16	106·22	0	0·57	0·29	16·10
	Septic Tank Effluent	—	" 13	1. 0 a.m.	46	43	8·28	4·56	12·84	39·4	9·49	2·47	0·90	0	—	115·10	0	1·53	Traces	16·69
	Lower Contact Bed Effluent ...	—	" "	7. 0 "	44	46	Traces.	Traces.	Traces.	36·9	1·47	0·20	0·20	0	0·45	121·21	1·43	0	0	18·67
3	Crude Sewage	0·370*	Feb. 2	3.30 p.m.	46	39·5	17·52	13·36	30·88	40·0	9·11	1·43	1·00	0	0·14	—	—	—	—	—
	Screened and Settled Sewage...	—	" "	7.30 "	46	40	—	—	—	37·5	8·60	1·48	1·00	0	0·12	89·51	0·84	0·32	0	15·87
	Septic Tank Effluent	—	" 3	1. 0 a.m.	44	40	6·76	4·76	11·52	45·0	7·03	2·80	0·66	0	—	115·67	0·00	1·07	0	16·86
	Lower Contact Bed Effluent ...	—	" "	7. 0 "	40	38	?	?	0·80	50·0	1·63	0·41	0·26	0	1·47	94·55	1·63	0	0	19·24
4	Crude Sewage	0·00†	July 21	3.30 p.m.	66	64	—	—	—	—	10·18	2·47	1·32	—	—	—	—	—	—	—
	Screened and Settled Sewage...	—	" "	7.30 "	64	60	—	—	—	—	7·35	2·81	0·99	—	—	—	—	—	—	—
	Septic Tank Effluent	—	" 22	1. 0 a.m.	64	57	—	—	—	—	6·51	3·29	0·66	—	—	—	—	—	—	—
	Lower Contact Bed Effluent ...	—	" "	7. 0 "	62	59·5	—	—	—	—	1·82	0·41	0·33	—	—	—	—	—	—	—
5	Crude Sewage	0·02†	July 25	3.30 p.m.	66	62	—	—	—	—	10·43	2·47	1·23	—	—	—	—	—	—	—
	Screened and Settled Sewage...	—	" "	7.30 "	64	60	—	—	—	—	8·55	2·71	0·91	—	—	—	—	—	—	—
	Septic Tank Effluent	—	" 26	1. 0 a.m.	64	57	—	—	—	—	6·19	3·62	0·74	—	—	—	—	—	—	—
	Lower Contact Bed Effluent ...	—	" "	7. 0 "	60	55	—	—	—	—	1·62	0·33	0·33	—	—	—	—	—	—	—
6	Crude Sewage	0·00†	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Screened and Settled Sewage...	—	Dec. 21	7.30 p.m.	—	—	—	—	—	25·6	4·21	2·71	0·49	—	—	—	—	—	—	—
	Septic Tank Effluent	—	—	—	—	—	—	—	—	28·0	3·98	2·55	0·49	—	—	—	—	—	—	—
	Lower Contact Bed Effluent ...	—	—	—	—	—	—	—	—	24·5	0·99	0·37	0·29	—	0·82	—	—	—	—	—

* Rainfall up to end of February, 1904, was taken from Queen's College records, at 9 a.m., for previous 24 hours.

† Rainfall subsequent to end of February, 1904, was taken from the automatic recording gauge at the Outfall Works, for the period of 24 hours preceding the time of collecting the crude sewage samples.

The following is a short summary of the average effects of this method of treatment on the more important factors, as indicated by both the older (series A) and the newer (series B) set of experiments, and also in both taken as a whole :—

	Series.	Average Actual Quantities in Parts per 100,000.		Percentage Purification.
Nitrogen as Free Ammonia ...	A	Screened and Settled Sewage 1·889	Purified Effluent 0·236	87
	B	„ „ „ „ 2·195	„ „ 0·325	85
	A and B	„ „ „ „ 2·011	„ „ 0·275	86
Nitrogen as Albuminoid Ammonia ...	A	„ „ „ „ 0·758	„ „ 0·208	73
	B	„ „ „ „ 0·852	„ „ 0·247	71
	A and B	„ „ „ „ 0·795	„ „ 0·223	72
Oxygen Absorbed Test	A	„ „ „ „ 6·956	„ „ 1·558	78
	B	„ „ „ „ 7·257	„ „ 1·437	80
	A and B	„ „ „ „ 7·077	„ „ 1·509	79
Nitrogen as Nitrates	A	„ „ „ „ 0·236*	„ „ 0·56†	
	B	„ „ „ „ 0·092‡	„ „ 0·76‡	
	A and B	„ „ „ „ 0·177	„ „ 0·62	

The most noteworthy and important feature in the analytical results obtained in the investigation was the high purification indicated as regards the free ammonia (most of which appears to be got rid of in the lower series of contact beds)—the actual purification in this factor being, as already stated, over 86 per cent. as the average of all the determinations compared with 51 per cent. found in the previous experiments on the purification brought about by treatment of the sewage with contact beds only.

The loss in albuminoid ammonia is not very different from that obtained by contact bed treatment only (average for the latter, 71 per cent.).

The loss in the Oxygen Absorbed test shows a decided improvement over that resulting from contact bed treatment only (average for the latter, 71 per cent.).

An important feature is the production of nitrates, which is in sharp contrast with the non-production of nitrates, and even their destruction, during the treatment of sewage by contact beds only.

How can this difference be accounted for?

The simplest explanation is that the anaerobic treatment in the septic tank "prepares" the sewage for subsequent aerobic treatment on the contact beds, and encourages both the loss of free or saline ammonia and the production of nitrates—this preparing action consisting of chemical changes induced either by indirect (enzymic) or direct bacterial action, whereby the more complex organic molecules are reduced to simpler ones. In other words, septic action may, and in all probability does, mark a step in the resolution of complex organic bodies into the simple compounds which are formed as ultimate products, namely, ammonia, nitric acid, and carbonic anhydride.

But an explanation of a totally different kind may also be suggested.

As before stated, it is well known that nitrates when in contact with putrefying organic matter are reduced to nitrogen gas.

In the septic tank a large proportion of the sewage solids (in suspension), including those of an organic nature, is removed merely by sedimentation, while a further quantity of the latter (varying, it is now believed, from about 12–25 per cent. of the original total) is resolved into gaseous products such as marsh gas, ammonia, nitrogen and hydrogen. The effluent from a septic tank is therefore considerably poorer in organic matter than the original sewage. Those who have studied the conditions under which nitrefication occurs agree that the presence of organic matter is inimical to the process, and therefore, for that reason alone, nitrefication should occur more readily in the effluent from the septic tank than in the original sewage.

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* Mean of 4 Series of Analyses. † Mean of 7 Series of Analyses. ‡ Mean of 3 Series of Analyses.

But in addition to this, supposing that nitrefication does occur to a certain extent when the latter is treated directly on contact beds: these beds in course of time become loaded with solid organic matter, and the conditions are consequently favourable to denitrefication. Under these circumstances it is not only possible, but also probable, that the latter process may occur to such an extent that the nitrates originally formed disappear and are resolved into nitrogen gas.

As denitrefication can only take place in the absence of dissolved oxygen, supposing that the above-named changes have occurred—that is to say, first nitrefication and then denitrefication—the effluent should be free from dissolved oxygen and also charged with an excess of nitrogen gas, both of which effects were, in point of fact, actually observed during the investigation on the effects of contact bed treatment only.

But on the other hand, it will be noticed that the effluent from septic tank and contact bed treatment in all the samples examined in relation to the gases they held in solution (table on page 174) contained a fair amount of dissolved oxygen (probably about one-fifth of the amount which the liquid could take up from air). But the analyses of the dissolved gases also indicate a slight but distinct increase in nitrogen during the period of septic action, and a very decided increase during the period of contact bed treatment.

The average figures for the dissolved nitrogen found were as follows:—

	Screened and Settled Sewage.	Septic Tank Effluent.	Lower Contact Bed Effluent.
Dissolved Nitrogen (c.c. per Litre at N.T.P.) ...	16·1	16·9	18·6

On first thoughts it may seem highly improbable that the excess of nitrogen found in the lower contact bed effluent could owe its origin to denitrefication, because, as already stated, that process only occurs in the absence of free oxygen, and the latter was found in the effluent.

But the difficulty in the explanation is an apparent one only, as we believe the following considerations will show:—

At a certain stage of the contact treatment the bed may be supposed to be charged with a liquid which is both aerated and nitrated.

The solid material of the bed contains organic matter, probably precipitated in films or layers on the surfaces of the solid fragments. Diffusion of the liquid occurs continuously both into and out of these layers of organic matter. The ingoing stream carries both nitrates and dissolved oxygen. The latter is first seized on and absorbed by the organic matter, and the liquid, now oxygen free, diffuses still further into the layer, and becomes denitrefied. The outgoing stream is now charged with nitrogen gas, but is free from dissolved oxygen, and mingling with the undiffused liquid produces a mixture which contains less oxygen but more nitrogen than was originally present.

Regarding the extent to which the changes occurring in contact beds are influenced by the size of the solid fragments in them, and by the nature of the medium of which the fragments are composed, it is, we believe, generally agreed that finer fragments are more efficient than those which are coarse, while there seems to be a difference of opinion as to whether the nature of the material affects the results.

Our own experiments are distinctly in favour of the view that the nature of the the material has a decided influence.

The following, among many experimental results, may here be given:—

A series of upper and lower contact beds was constructed of precisely the same dimensions, which were filled with different materials graded as to size of fragments as explained in the table of results.

All of these beds were simultaneously charged from the same septic tank, so that the results as to purification effected are strictly comparable.

The following results were obtained :—

EXPERIMENTS ON THE USE OF DIFFERENT MATERIALS IN CONTACT BEDS.

Average Results.

Liquid Analysed.	Filling Material.		Parts per 100,000.				
	Nature.	Grade.	Suspended Solids.	Oxygen absorbed Test (4 hrs. at 80° F.).	Nitrogen as :—		
					Free Ammonia.	Albuminoid Ammonia.	Nitrates.
Crude Sewage	—	—	34·07	9·19	1·97	1·24	0·13
Screened and Settled Sewage...	—	—	—	7·26	2·19	0·85	0·09
Septic Tank Effluent ...	—	—	11·37	6·16	2·70	0·67	—
Effluent from Double Contact	Broken Brick	Medium and Fine	0·66	1·44	0·32	0·25	0·76
" " ...	Freestone	"	—	2·50	1·03	0·33	—
" " ...	Whinstone	"	—	1·97	0·85	0·29	—
" " ...	Clinker	"	—	2·30	1·40	0·38	—
" " ...	Coke	"	—	1·99	1·07	0·33	—
" " ...	Limestone	"	—	2·31	0·98	0·24	0·47
" " ...	Ditto	Coarse & Medium	—	1·75	0·96	0·21	0·42

"Coarse" = Fragments passing through a riddle 2½ in. mesh, but rejected by one of 1½ in.
"Medium" = " 1½ " " ½ "
"Fine" = " ½ " " ⅛ "

In the following table the above results are presented in a different way :—

Material.	Grade.	Number of Analyses.	Percentage Purification * in		
			Oxygen Absorbed.	Free Ammonia.	Albd. Ammonia.
Broken Brick...	Medium and Fine	6	80	85	71
Freestone	" "	3	68	37	64
Whinstone	" "	3	75	48	68
Clinker	" "	2	71	49	61
Coke	" "	2	75†	61	64
Limestone	" "	4	74	49	74
Ditto	Coarse and Medium ...	5	78	54	76

* Referred to Screened and Settled Sewage.
† Two Series of Analyses.

The following table may be of interest in relation to the extent of some of the changes occurring in the Septic Tank as determined by different observers.

CHANGES OCCURRING IN THE SEPTIC TANK.

Year.	Locality.	Analyst.	Nitrogen as :— Free Ammonia. Parts per 100,000. Sewage.	Septic Tank Effluent.	Percentage Increase (I) or Decrease (D)	Albuminoid Ammonia. Parts per 100,000. Sewage.	Septic Tank Effluent.	Percentage Increase (I) or Decrease (D.)
1896	Exeter ...	S. Rideal ...	3·6	4·9	I 36	1·40	0·64	D 54
,,	,, * ...	,, ,, ...	8·5	11·2	I 32	4·3	2·66	D 38
1899	Caterham †	,, ,, ...	13·2	14·9	I 13	4·0	2·70	D 33
1899–1900	Leeds ...	W. H. Harrison	1·94	1·58	D 19	0·87	0·35	D 61
1900–1901	Manchester	G. Fowler ...	1·67	1·65	D 1	1·78	0·95	D 46
1903–1904	Belfast ‡ ...	E. A. Letts ...	2·21	2·70	I 12	0·85	0·67	D 21
1902–1903	,, § ...	,, ,,	1·89	1·92	I 2	0·76	0·72	D 6
1906–1907	,, ¶ ...	,, ,,	2·77	2·82	I 1	—	—	—

All the observations agree in showing a loss in albuminoid ammonia as the result of septic action, and the majority in showing the converse as regards free ammonia, as was to be anticipated, and further that the development of free ammonia is dependent on the length of the period of septic action.

It is difficult to find an explanation for the decrease in free ammonia observed in the Leeds experiments.

3. *Effects of treating Sewage by a Septic Tank and Continuous or Sprinkling Filters. First Experiments.*

This method of sewage treatment is we believe coming more and more into favour, and its introduction marks a distinct advance in the methods of sewage treatment generally. We shall discuss its advantages later on.

In our first experiments to test the effects of this system of sewage purification, the "sprinkler" used was of the revolving type (Mather and Platt) and was intermittent in action, discharging for a period of three minutes after a rest of seven minutes in the first six experiments, and in the remainder the period of rest was nine and a quarter minutes. The following particulars may be given:—

Height of filter bed - - - - - - - - - -	4 feet.
Diameter - - - - - - - - - -	20 feet.
Area - - - - - - - - - -	about 35 square yards.
Quantity of sewage treated per cubic yard of medium per 24 hours - - - - -	Series 1–6 - - 195 gallons. ,, 7–14 - - 150 ,,

The filter bed was arranged in quadrants to test the effects of different kinds and different grades of materials, but as the experiments on these points were made later a joint sample from all four quadrants was examined. The nature and size of the material in the four quadrants were as follows:—

Quadrant 1, Burnt sleech, 2 inch to 1 inch (with air space below).
,, 2, ,, ,, ,, (without air space below).
,, 3, Broken brick ,, ,,
,, 4, Destructor clinker, 2 inch to 1 inch.

---

* Calculated on a uniform basis of 7 parts of chlorine per 100,000.
† The figures refer to nitrogen as free ammonia and organic nitrogen respectively
‡ 19 hours septic action.
§ 12 ,, ,,
¶ 6 ,, ,,

The following is a summary of the chief results obtained:—

Average Actual Quantities in Parts per 100,000.				Percentage Purification.
Nitrogen as Free Ammonia... ...	Septic Tank Effluent	Series 1— 6	3·078	
	„ „	„ 7—14	2·734	
	Sprinkler „	„ 1— 6	0·911	70
	„ „	„ 7—14	0·337	88
Nitrogen as Albuminoid Ammonia... ...	Septic Tank „	„ 1— 6	0·685	
	„ „	„ 7—14	0·590	
	Sprinkler „	„ 1— 6	0·346	50
	„ „	„ 7—14	0·173	71
Oxygen Absorbed Test (4 hours at 80° F.)	Septic Tank „	„ 1— 6	6·38	
	„ „	„ 7—14	6·33	
	Sprinkler „	„ 1— 6	2·44	62
	„ „	„ 7—14	2·04	68
				Percentage of Nitrogen as Nitrate in Effluent referred to the Ammonia in the Septic Tank Effluent.
Nitrogen as Nitrate ...	Sprinkler „	„ 1— 6	1·555	50
	„ „	„ 7—14	1·608	59

These results, so far as purification is concerned, are not very different from those obtained by septic tank and double contact bed treatment, but a much higher proportion of nitrate was produced.

Second Experiments.

In a second series of experiments a different form of sprinkler and a different sprinkler bed were employed.

The sprinkler was devised by Mr. Cutler, City Surveyor of Belfast, and consisted of four radial troughs 2¼ in. wide and 2⅝ in. deep, connected at their ends with two concentric annular troughs, the whole being slung by tie rods from a cap resting on a fixed central column round which the troughs revolved. The septic tank effluent was supplied by two nozzles, which discharged into the outside annular trough, and the motive power was obtained by the jets from the nozzles impinging on vanes fixed inside the trough. The radial troughs were perforated with holes arranged so as to distribute the sewage over the surface in quantities proportional to the area commanded by each hole.

The following particulars may be given:—

Height of sprinkler bed - - - - - - 5 ft.
Diameter „ „ - - - - - - 12 ft.
Area „ „ - - - - - - 12½ square yards.
Material „ „ - - - - - - Limestone fragments.
Grade of material 2½ in. below to ¼ in. at top.
Sewage treated per square yard of medium per 24 hours—290 gallons.
„ „ „ cube „ „ „ „ „ „ 174 „
Period of septic action—19 hours*

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* Previous to reaching the septic tank the sewage was stored in another tank for a period varying from 1 to 5 hours.

The following is a summary of the chief results obtained :—

SECOND EXPERIMENTS—MEAN OF 7 SERIES OF ANALYSES.

Average Actual Quantities in Parts per 100,000.			Percentage Purification.
Nitrogen as Free Ammonia ...	Septic Tank Effluent	2·794	—
	Sprinkler „	0·929	67
Nitrogen as Albd. Ammonia ...	Septic Tank „	0·607	—
	Sprinkler „	0·201	67
Oxygen Absorbed Test ...	Septic Tank „	6·40	—
	Sprinkler „	2·31	64
			Percentage of Nitrogen as Nitrate in Effluent referred to Nitrogen as Ammonia in the Septic Tank Effluent.
Nitrogen as Nitrate	Sprinkler „	1·394	50

Third Experiments.

The following preliminary experiments were made mainly with the object of testing the effects of different "filling" materials in the sprinkler bed.

The latter was of the same size as in the first series, and was arranged in quadrants, each of which contained either a different material or a different grade of the same material, and was provided with an arrangement for collecting the effluent from each quadrant separately. The sprinkling arrangement was the same as that used in the first series. By this means the same sewage was simultaneously submitted to beds of either different materials or different grades of the same material in such a way that the results are strictly comparable with each other.

The following is a summary of the results obtained :—

EFFECTS OF DIFFERENT MATERIALS IN A SPRINKLER BED.

	Mean Results in Parts per 100,000.				
Sample.	Oxygen Absorbed Test (4 hrs. at 80°F.)	Nitrogen as :—			
		Free Ammonia.	Albd. Ammonia.	Nitrate.	Nitrite.
Screened and Settled Sewage	5·60 (5*)	2·990 (5)	0·599 (4)	—	—
Septic Tank Effluent	5·74 (5†)	3·030 (5)	0·547 (4)	—	—
Burnt Sleech 2½″—1½″ (with air space below)	2·36 (4)	1·767 (4)	0·225 (2)	0·491 (3)	0·18 (3)
Limestone 2½″—1½″	2·59 (2)	2·350 (2)	0·360 (1)	0·301 (1)	0·00 (2)
Broken Brick 2″—1″	1·73 (5)	0·635 (5)	0·174 (3)	1·563 (4)	0·00 (5)
Sandstone** 2½″—1½″	2·97 (3)	1·917 (3)	0·321 (2)	0·432 (2)	0·12 (3)

Percentage Purification
(On the Screened and Settled Sewage).

Burnt Sleech	57	40	57	16††	6††
Limestone	50	21	36	9††	0††
Broken Brick	69	79	72	51††	0††
Sandstone...	43	30	39	8††	4††

The figures in brackets refer to the Number of samples analysed.

* Including 1 Septic Tank Effluent.

† Including 1 sample of Screened and Settled Sewage.

** 2in.—1in. in First Series.

†† The figures refer to Percentage of Nitrogen as Nitrate or Nitrite calculated on the Nitrogen as Ammonia in the Screened and Settled Sewage.

Although the number of determinations made with the different materials was no doubt too small to warrant very definite conclusions, the results, so far as they go, confirm the good opinion previously formed of the superior efficiency of the broken brick material in relation to contact beds. The burnt sleech is of a similar nature, but its efficiency was considerably less, and it is difficult to see any reason for believing that the air-space beneath it could have acted inimically, except by reducing the depth of the column.

The number of determinations made in the effluent from the limestone quadrant was small, and the results, such as they are, compare very unfavourably with those obtained in Series 2, where the same material was employed as in the sprinkler bed.

The number of determinations made in the effluent from the sandstone quadrant was also small, but they confirm the unfavourable opinion of this material as a filling for contact beds, not alone from the comparative experiments described on p.177, but also from the character of the effluent obtained from certain large beds at Belfast, which were filled with this material and have been in operation for some years.

Fourth Experiments.

In these the sprinkling arrangement was that employed in the preceding series of experiments, but the bed was reconstructed.

The following particulars may be given :—

Height of Sprinkler Bed - - - - - - - - -	5 ft. 6 in.
Diameter " " - - - - - - - - -	12 ft.
Area " " - - - - - - - - -	12½ square yards.
Material " " - - - - - - - - -	Burnt "Sleech."
Grade of Material - - - - - - - - - -	1–½ in.
Sewage treated per square yard of medium per 24 hours - - -	300 gals.
" " " cubic " " " " " " - - -	164 gals.

It may be mentioned that several objects were aimed at in making the experiments of this series, of which the chief were :—

(1) The effects of different periods of septic action or sedimentation, the periods chosen being 24, 12, and 6 hours.

(2) The extent of the changes occurring at different depths of the sprinkler bed, for which purpose samples were drawn at depths of 2, 4, and 5½ feet from the surface.

(3) Certain experiments on denitrification, to be described presently.

The following table contains a summary of the results obtained :—

FOURTH EXPERIMENTS—SUMMARY OF RESULTS.

Period of Septic Action or Sedimentation	24 hours	12 hours	6 hours
Number of Experiments made ...	3	3	20

MEAN RESULTS IN PARTS PER 100,000.

	Nitrogen as :		Nitrogen as :		Nitrogen as :	
	Free Ammonia.	Nitrate.	Free Ammonia.	Nitrate.	Free Ammonia.	Nitrate.
Crude Sewage	1·290	—	2·040	—	2·776	
Tank Effluent	2·873	—	2·417	—	2·810	
Sprinkler Effluent 2 feet ...	2·250*	0·590	1·750	0 500	—	
Sprinkler Effluent 4 " ...	1·185	1·625	0·407	1·550	—	
Sprinkler Effluent 5½ " ...	0·158	1·767	0·060	1·917	0·114	2·197

PERCENTAGE PURIFICATION IN FREE AMMONIA AND PERCENTAGE OF FREE AMMONIA CONVERTED INTO NITRATE.

Sprinkler Effluent 2 feet ...	—64*	43	15	22		
Sprinkler Effluent 4 " ...	14	118	80	76		
Sprinkler Effluent 5½ " ...	88	137	97	94	96	79

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* The results are referred to crude sewage and not to the septic tank effluent, which accounts for apparent negative purification at this depth in the Sprinkler bed.

It may be noted that as the free ammonia and nitrates are chiefly concerned in the Belfast problem, other determinations were not made.

Regarding the effects of different periods of septic action or sedimentation: for several reasons the shorter the period the better, provided that efficient purification is induced later, and this is especially the case at Belfast, as prolonged septic action gives rise to ammonia. From the above table of results it appears that a period of six hours for sedimentation is sufficient, and only causes a rise of about one per cent. in the free ammonia.

Regarding the extent of the changes occurring at different depths of the sprinkler bed, it may be mentioned that the results of one set of experiments are not given fully in the above summary. In this set the period of sedimentation was six hours, and the figures for the percentage reduction in ammonia and the percentage of free ammonia converted into nitrate respectively were as follows :—

		Ammonia.	Nitrate.
Sprinkler Effluent	2 feet	23	31
	4 „	80	78
	5½ „	100	87

Although the number of experiments made was insufficient, perhaps, to warrant any detailed conclusions, we think it may be safely assumed that under the given conditions (1) a depth of 5½ feet in the sprinkler bed suffices for efficient purification, and (2) that the extent of the changes in the soluble constituents of the sewage is greatest below a depth of 2 feet.

Finally, it may be mentioned that in the last eight experiments no free ammonia at all could be detected in the sprinkler effluent. Whether this was due to the bed having got into a thoroughly efficient condition, or was caused by the warmer weather, we have no means of deciding.

From the results described above on the three different methods of sewage purification, it will be seen that in all cases where a high proportion of free ammonia was got rid of, nitrates made their appearance in the effluent.

In places like Belfast, where the main object of sewage purification is the suppression of a nuisance caused by the growth and subsequent decay of large quantities of green sea-weeds—more especially the *ulva latissima*—the ideal effluent to be aimed at for discharge into the sea is one which, as already said, shall be free from both ammonia and nitrates, as each of these substances encourages the growth of the green sea-weeds. Elsewhere in this report, however (see p. 159), it is shown that the latter absorb nitrates at only about one-third of the rate at which they absorb the equivalent quantity of ammonia—a point which ought not to be left out of consideration. Meanwhile, it appeared as a fact established from the above experimental investigations, that while an effluent virtually free from ammonia can be produced, it can only be obtained at the expense—so to speak—of nitrate production.

Such being the case, the next branch of the inquiry to which attention was devoted was the possibility of removing these nitrates from the purified effluent.

The following is an account of the investigations which one of us has made on this subject, either alone or in collaboration with others.

The Chemical Changes which occur when Potassium Nitrate is added to the Effluent from a Septic Tank.[*]

The method of experiment consisted in completely filling two similar bottles (which were then tightly stoppered) one with the septic tank effluent alone and the other with the same effluent plus an accurately measured volume of a strong solution of potassium nitrate, one cubic centimetre of which was equivalent to ten milligrams of nitric nitrogen—allowing the two bottles so filled to remain at the temperature of the laboratory for a given interval of time, and then examining their contents quantitatively, and more particularly as regards the dissolved gases.

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[*] The experiments on this subject were made in collaboration with Mr. R. F. Blake, F.I.C., F.C.S., and Mr. J. H. Totton, M.A.

With one exception all the experiments were made with mixtures of potassium nitrate and septic tank effluent, containing 2·5 parts of nitric nitrogen per 100,000 of mixture in the case of the nitrated samples.

The analysis of the dissolved gases was both tedious and troublesome in many of the experiments, owing partly to the complexity of the gas mixtures to be examined and partly to the small quantities available for analysis. Moreover, in the earlier experiments certain difficulties were encountered which rendered the complete analysis of the dissolved gases very uncertain, and as a consequence there is some doubt as to the extent of the evolution of nitrogen in the earlier experiments of the nitrated series.

Table 1 contains the chief results obtained, while on Table 2 some of them are presented in a different form, together with certain other data.

TABLE 1.

DISSOLVED GASES FOUND IN SEPTIC TANK EFFLUENTS (A) WITH ADDED POTASSIUM NITRATE AND (B) ALONE AFTER CERTAIN INTERVALS OF TIME.

(Results in cubic centimetres per litre at 0° C. and 760 m.m.)

		1.	2.	3.	4.	5.	6.
						Non-Aërated.	Aërated.
	Nitric nitrogen added in parts per 100,000	2·5	5·0	2·5	2·5	2·5	2·5
	Time interval in hours...	48	24	24	24	24	24
A Nitrated sample.	Carbonic anhydride	169·97	155·68	153·34	158·01	165·85	149·63
	Nitrogen	38·12	29·40	34·21 ?	32·41	36·16	33·53
	Nitric oxide	?	?	6·99	6·31	0·00	0·00
	Marsh gas	?	?	?	3·37	2·63	0·00
	Oxygen	0·00	0·00	0·00	0·00	0·00	0·00
B Septic tank effluent.	Carbonic anhydride	126·68	150·99	118·10	127·31	120·44	92·52
	Nitrogen	18·84	18·86	15·62	16·55	16·48	13·94
	Marsh gas	?	?	1·91*	2·92	1·72	0·14 ?
	Oxygen	0 00	0·00	0·00	0·00	0·00	5·33
Differences.	Carbonic anhydride (excess in nitrated sample).	43·29	4·69	35·24	30·70	45·40	57·11
	Nitrogen as nitrogen and nitric oxide (excess in nitrated sample).	19·28 ?	10·54 ?	22·08 ?	19·12	19·68	19·59
	Marsh gas (excess in nitrated sample)	?	?	?	0·45	0·91	−0·14 ?

* $\left.\begin{array}{l}\text{Marsh gas } 1{\cdot}48\\ \text{Hydrogen } 0{\cdot}43\end{array}\right\}1{\cdot}91.$

TABLE 2.

EVOLUTION OF NITROGEN EITHER AS SUCH, OR IN THE FORM OF GASEOUS OXIDES, FROM SEPTIC TANK EFFLUENTS WITH ADDED POTASSIUM NITRATE. ALSO OTHER CHEMICAL CHANGES OCCURRING.

(Dissolved gases in cubic centimetres per litre at 0°C and 760 m.m. Other quantities in parts per 100,000.)

		1.	2.	3.	4.	5.	6.
	Nitric nitrogen added in parts per 100,000	2·5	5·0	2·5	2·5	2·5	2·5
	Time interval in hours	48	24	24	24	24	24
Dissolved gases.	Carbonic anhydride evolved in nitrate sample.	43·29	4·69	35·24	30·70	45·40	57·11
	Carbonic anhydride theoretical evolution*	49·80	99·60	49·80	49·80	49·80	55·13
	Nitrogen evolved in nitrated sample ...	19·28 ?	10·54 ?	22·08	19·12	19·68	19·59
	Theoretical evolution	19·90	39·80	19·90	19·90	19·90	19·90
Free and albuminoid ammonia.	Nitrogen as free ammonia in septic tank effluent alone.	2·14	3·43	1·98	2·06	1·84	—
	Nitrogen as albuminoid ammonia in septic tank effluent alone.	0·58	0·58	0·49	0·66	0·50	—
	Nitrogen as free ammonia in septic tank effluent plus nitrate.	1·48	3·30	1·89	1·81	1·58	—
	Nitrogen as albuminoid ammonia in septic tank effluent plus nitrate.	0·66	0·74	0·57	0·66	0·66	—
	Excess of nitrogen as free ammonia in septic tank effluent alone.	0·66	0·13	0·09	0·25	0·26	—
	Excess of nitrogen as albuminoid ammonia in nitrated sample.	0·08	0·16	0·08	0·00	0·16	—
Nitrites.	Nitrogen as nitrite in nitrated sample ...	—	0·11	0·05	0·00	0·00	0·00
	,, ,, ,, non-nitrated sample	—	0·00	0·00	0·00	0·00	0·00

The chief general conclusions arrived at may be summed up as follows:—

(1) Potassium nitrate (and no doubt any other nitrate likely to be produced in a sewage effluent) is decomposed by the septic tank effluent, and the nitric nitrogen is evolved, sometimes entirely as free nitrogen, sometimes partly as nitric oxide. Nitrous oxide may also be formed, but the evidence on that point is not as yet conclusive.† The action seems to vary with different samples of septic tank effluent, but in four of the eight experiments the theoretical quantity of nitrogen (corresponding with the added nitrate) was found either as free nitrogen alone or along with nitric oxide.

There is no evidence from our experiments to show that any considerable quantity of these gases is produced from either the free ammonia or the organic nitrogen present in the septic tank effluent.

(2) The general character of the change is that of a combustion, the oxygen of the nitrate eventually appearing either partly or entirely in the form of carbonic anhydride.

(3) In some of the experiments a little nitrite was produced, but in the majority none was found at their conclusion.

(4) The destruction of the nitrate occurs with remarkable rapidity, and in most of the experiments the whole of the added nitrate—equivalent to 2·5 parts of nitric nitrogen per 100,000 of mixture—was decomposed in 24 hours.

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* *i.e.*, the carbonic anhydride equivalent to the oxygen of the added nitrate.

† Gayon and Dupetit found all three gases.

A remarkable exception to this rule is, however, noticed in the case of Experiment 2, in which the quantity of nitrate added was twice as great as in the other experiments. Here the evolution of carbonic anhydride is trifling, and that of the nitrogen very considerably less than in the other experiments.

It is, perhaps, not safe to arrive at general conclusions from a single experiment, but it would at least seem probable that, while a certain quantity of nitrate is readily decomposed and acts as an ozidising agent, burning up the carbon of the sewage to carbonic anhydride, there is a limit to the quantity which can thus be decomposed, beyond which excess of nitrate retards or possibly prevents the action.

(5) In addition to the decomposition of the nitrate and evolution of carbonic anhydride the fermenting liquid experiences other changes.

There is always a *loss* of free ammonia, and as a rule a *gain* in albuminoid ammonia, but the former generally exceeds the latter. Thus in six experiments the average loss of free ammonia amounted to 0·266 part per 100,000, while the corresponding gain in albuminoid ammonia was only 0·166, or rather less than half the preceding figure.

It may also be mentioned that in two of the experiments marsh gas was found, not only in the septic tank effluent, but also in the nitrated fluid, and it is somewhat remarkable that more of the gas was found in the latter than in the former.

Towards the end of the investigation the effects of aëration were studied. Parallel experiments were made, in one of which the septic-tank effluent was thoroughly aërated before mixing it with the nitrate, while in the other the same quantity of nitrate was added to the non-aërated effluent. In both experiments the whole of the nitrate was decomposed in twenty-four hours with evolution of the equivalent quantity of nitrogen gas. In the aërated sample no marsh gas was formed, but a considerable excess of carbonic anhydride was produced, the total volume per litre of fluid being 57·1 c.c., whereas the amount corresponding with the added nitrate *plus* the oxygen dissolved from the air was 49·8 + 5·53 = 55·33. In the non-aërated sample some marsh gas was formed, but considerably less carbonic anhydride.

Cause of the Decomposition of Nitrates when in contact with a Putrefying Liquid.

In order to ascertain whether the action was brought about entirely by the vital processes of micro-organisms, and was not due to enzymes excreted by them or to purely chemical changes, an apparatus was devised in which the septic-tank effluent was passed through a Chamberland filter and thence into a sterilised flask from which it was drawn by a vacuum pump into two sterilised tubes of sufficient capacity, one of which contained a measured volume of the nitrate solution, and these tubes when filled were closed by pinch-cocks applied to indiarubber junctions. At the end of sixty-six hours analyses were made of the dissolved gases contained in the liquids of both tubes, when the following results were obtained (in cubic centimetres per litre at N.T.P.) :—

Gases present.	In Nitrated Sample.	In Non-nitrated Sample.
Carbonic Anhydride	92·12	94·45
Oxygen...	0·00	0·00
Nitrogen	1·62	2·00

The figures are not absolutely identical, but are nearly so.

The reason for the excess of dissolved gases in the non-nitrated sample is easily explained, as the liquid yielding these gases was drawn from the lower layers in the flask, which had not been exposed to the vacuum so long as the upper layers, from which the liquid for the nitrated sample was drawn.

The somewhat large quantity of carbonic anhydride found in the analysis is no doubt due to the presence of carbonates or bicarbonates in the fluid, and not to free carbonic anhydride.*

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* For it should be recollected that before extracting the dissolved gases, acid was added to the liquids to decompose carbonates.

It is, however, quite obvious that no nitrate was decomposed, and the results of this experiment appear to be decisive.

The septic tank effluent deprived of the micro-organisms which it contains has no action upon a nitrate, and the decomposition of the latter must be caused entirely by the vital processes of certain micro-organisms and not by enzymic or chemical action.

The experiments just described indicated that it is quite possible to destroy the nitrates in a sewage effluent with considerable rapidity in such a way as to prevent them from serving as a food or manure for vegetation, as it need scarcely be mentioned that free nitrogen is not assimilated by plants except in one or two exceptional cases. They also point to a method of sewage purification suitable for a locality like Belfast, where the main object is the prevention of excessive vegetable growth—the broad features of such a method being :—

(1) Purification of part of the sewage by septic tank and contact beds, whereby most of the ammonia is got rid of, while a certain amount of nitrate is produced ; and

(2) Treatment of this effluent with a certain proportion either of the original sewage or of the septic tank effluent, by which means the nitrate would be got rid of.

As a preliminary step towards the working out of a practical method for most advantageously combining the two processes, the following experiments were tried :—

Nitrates and nitrites having been determined in the contact bed effluent, a certain volume of the latter was placed in a bottle, and to it a definite proportion of the septic tank effluent was added. The bottle was about half filled with the mixture, and no precautions were adopted to exclude air.

After an interval of twenty-four hours, during which the bottle and its contents remained at the temperature of the laboratory, determinations of nitrate and nitrite were again made, and the results then obtained, so calculated as to give the quantities of these present—not in parts per 100,000 of the mixture, but in parts per 100,000 of the nitrated effluent contained in the mixture. The following table contains the results of these experiments :—

LOSS OF NITROGEN AS NITROGEN GAS OR GASEOUS OXIDES OF NITROGEN OCCURRING IN A MIXTURE OF THE SEPTIC TANK EFFLUENT WITH THE SAME AFTER TREATMENT ON CONTACT BEDS.

Nitrogen present as Nitrite and Nitrate (parts per 100,000).											Loss of Nitrogen.	
In the Nitrated Effluent.							Composition of the Mixture.	Calculated as present in the same Effluent 24 hours after mixing it with the Septic Tank Effluent.			Actual (parts per 100,000).	Percentage.
Number of Experiment.	On Mixing.			After 24 hours.								
	Nitrite	Nitrate	Total.	Nitrite	Nitrate	Total.		Nitrite	Nitrate	Total.		
1	–	–	0·82	–	–	0·82	4 volumes nitrated effluent and 1 volume septic tank effluent	–	–	0·55	0·27	33
2	0	0·66	0·66	0	0·66	0·66	4 ,, ,,	0·22	0·03	0·25	0·41	62
3	0	0·58	0·58	0	0·58	0·58	2 ,, ,,	0·0	0·09	0 09	0·49	85
4	0	0·82	0·82	–	–	–	4 ,, ,,	0·0	0·0	0·0	0·82	100
							3 ,, ,,	0·0	Trace	Traces	nearly 0·82	nearly 100
5	Traces	nearly 2·16	2·16	–	–	–	4 ,, ,,	0·87	0·93	1·80	0·36	17
							3 ,, ,,	0·84	0·93	1·77	0·39	18

It will be seen that in every case nitrates were reduced, and partly at least converted into gaseous nitrogen, while in some of the experiments all the nitrates were thus disposed of. Some other features in the results may be drawn attention to. Thus, the greatest loss of nitrogen occurred when no nitrites were produced, and conversely the least loss of nitrogen took place when nitrites were formed in considerable quantities. Also it will be seen that no reduction of the nitrates occurred in the nitrated effluent alone when kept for 24 hours, showing probably that the organic matters originally present had been oxydized, for the time being at all events, as far as possible.

A second series of experiments was made in a similar way to those just described, with the difference, however, that the effluent from a "sprinkler" was substituted for that from the contact beds previously employed. The subjoined table contains the results of this series :—

LOSS OF NITROGEN AS NITROGEN GAS OR GASEOUS OXIDES OF NITROGEN OCCURRING IN A MIXTURE OF THE SEPTIC TANK EFFLUENT WITH THE SAME AFTER TREATMENT BY A SPRINKLER.

Number of Experiment.	Nitrogen present as Nitrites and Nitrates (parts per 100,000).							Loss of Nitrogen.	
	In the Nitrated Effluent as—			Composition of the Mixture.	Calculated as present in the same Effluent 24 hours after mixing it with the Septic Tank Effluent.			Actual (parts per 100,000).	Percentage.
	Nitrite.	Nitrate.	Total.		Nitrite.	Nitrate.	Total.		
1	—	—	1 318	4 vols. Nitrated Effluent and 1 vol. Septic Tank Effluent	—	—	1·132	0·186	14·1
2	None	1·318	1·318	4 " " "	0·25	0·987	1·237	0·083	6·1
3	Traces	—	1·515	4 " " "	0·50	0·837	1·337	0·178	11·9
4	0·125	1·275	1·400	3 " " "	0·53	0·678	1·208	0·192	13·7
				1 " " "	0·80	0·102	0·902	0·498	35·6
5	Traces	—	1 980	4 " " "	Traces.	1·850	1·850	0·130	6·6
6	0·100	2·370	2·470	4 " " "	0·125	2·035	2·160	0·310	12·5

The results of this series are on the whole very different from those of the first, the reduction of nitrates to nitrogen being so much less. The explanation of this difference very possibly lies in the fact that whereas in the first series the nitrated effluent was known by experience to contain only small quantities of dissolved oxygen (1·5 c.c. per litre, as a mean of three determinations), that used in the second was much more highly aerated (6·53 c.c. per litre, as a mean of three determinations). But at the same time it should be remarked that the proportion of nitrates present in the two nitrated effluents was very much higher in the second series (sprinkler) than in the first (contact bed), with the exception of No. 5 of the first series, where the smallest loss of nitrogen of that series occurred.

It is somewhat difficult to find a completely satisfactory explanation of the incomplete reduction of nitrates in all the experiments of the second and in some of the experiments of the first series, compared with the complete reduction which occurred in the experiments described above, in which potassium nitrate was added (in concentrated solution) to the septic tank effluent.

The conditions, however, in the last-named experiments were by no means the same as those under which the others were conducted. In the first place, in all the experiments with potassium nitrate the bottles were filled to the brim and then stoppered; while in the second place, as the nitrate was added to a concentrated solution, the ratio of oxydizable matter to nitrate was obviously much higher in these experiments than in those in which a relatively large volume of nitrated effluent (presumably fairly free from readily oxydizable matters) was mixed with a small volume of the septic tank effluent.

* * * * *

From the results of the experiments just described, it is evident that given sufficient time and sufficiently large storage tanks, the effluents obtained during the treatment of sewage by the septic tank and contact beds or sprinklers can be made to re-act upon each other in such a way that the nitrates in the latter are partially resolved into nitrogen gas, and therefore destroyed.

But it is scarcely necessary to say that one of the chief objects to be kept in view in the treatment of sewage is to "hurry up" the purifying processes as rapidly as possible, while another is to reduce the volume of the sewage under treatment to the smallest practicable limit. The next experiments were therefore made with the view of ascertaining to what extent economy in both time and storage capacity was possible in relation to the destruction of nitrates. They were suggested by the view already given regarding the function of contact beds in relation to the formation and destruction of nitrates. The idea presented itself that by submitting a mixture of a highly nitrated effluent with either untreated sewage or the effluent from a septic tank to treatment on a contact bed, a double effect might be induced, namely, the destruction of nitrates in the first and purification in the second.

To test this point, an experimental plant of the following description was installed at the sewage works: immediately below the sprinkler and the open septic tank already referred to, a "mixing tank" was constructed with an arrangement for filling it with definite proportions of the septic tank and sprinkler effluents. Below this mixing tank a small contact bed was constructed.*

This arrangement was designed in order to permit of the following course of treatment:—A certain volume of the septic tank effluent passed through the sprinkler and its bed, and thence made its way into the mixing tank, where it became mingled with a definite proportion of untreated septic tank effluent. Thence the mixture of the two flowed into the upper contact bed, or "denitrefying bed" as it came to be called, where it remained for three hours, after which it was drawn off, the bed allowed to remain empty for three hours, and the same cycle of operations again repeated.

As the same liquid—namely, the septic tank effluent—was the starting point from which both the effluent from the sprinkler and the denitrefying bed was obtained, the chemical condition of these latter could be referred directly to that of the former.

In all, six series of experiments were made with this installation, the results of which are given in the following table:—

FIRST EXPERIMENTS.

EFFECTS PRODUCED (A) WHEN A SEPTIC TANK EFFLUENT IS TREATED BY A SPRINKLER AND (B) WHEN A MIXTURE OF THE SEPTIC TANK AND SPRINKLER EFFLUENTS IS TREATED ON A "DENITREFYING BED."

Series.	Date (1905).	Time of Collection.	Sample Analysed.	Nature of Mixture.	Parts per 100,000.				
						Nitrogen as :—			
					Oxygen Absorbed. (4 hrs. at 80° F)	Free Ammonia.	Albuminoid Ammonia.	Nitrates.	Nitrites.
1	Jan. 25th	4 a.m.	Septic Tank Effluent ...	1 volume	7·98	3·46	0·70	—	—
	Jan. 25th	4 a.m.	Sprinkler Effluent ...	1 "	2·68	1·48	0·39	1·32	—
	Jan. 25th	7 a.m.	Denitrefying Bed Effluent	... ...	3·05	1·48	0·37	0·82	0·0
2	Feb. 1st	4 a.m.	Septic Tank Effluent ...	1 volume	6·24	3·30	0 74	—	—
	Feb. 1st	4 a.m.	Sprinkler Effluent ...	1 "	2·59	1·07	0·33	1·32	traces.
	Feb. 1st	7 a.m.	Denitrefying Bed Effluent	... ...	2·96	1·40	0·37	0·00	0·0
3	Feb. 8th	4 a.m.	Septic Tank Effluent ...	1 volume	6·88	2·96	0·74	—	—
	Feb. 8th	4 a.m.	Sprinkler Effluent ...	1 "	2·56	0·74	0·37	1·51	traces.
	Feb. 8th	7 a.m.	Denitrefying Bed Effluent	... ...	3·04	1·32	0·37	0·00	0·0
4	Feb. 15th	4 a.m.	Septic Tank Effluent ...	1 volume	7·28	3·62	0·82	—	—
	Feb. 15th	4 a.m.	Sprinkler Effluent ...	1 "	3·05	1·43	0·41	1·40	0·12
	Feb. 15th	7 a.m.	Denitrefying Bed Effluent	... ...	3·01	1·48	0·45	0·00	0·0
5	Feb. 21st	10 p.m.	Septic Tank Effluent ...	1 volume	5·95	2·58	0·62	—	—
	Feb. 21st	10 p.m.	Sprinkler Effluent ...	1 "	2·27	0·49	0·29	1·98	traces.
	Feb. 22nd	1 a.m.	Denitrefying Bed Effluent	... ...	2·49	0·95	0·37	0·00	0·0
6	Feb. 28th	10 p.m.	Septic Tank Effluent ...	4 volumes	5·33	3·29	0·47	—	—
	Feb. 28th	10 p.m.	Sprinkler Effluent ...	3 "	2·07	0·56	0·27	2·46	0·01
	Mar. 1st	1 a.m.	Denitrefying Bed Effluent	... ...	2·27	0·93	0·27	0·25	0·0

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* This bed was filled with fragments of broken brick fragments to a depth of 1½ feet, and the latter were ¼ inch in diameter. For the sake of convenience this bed has been called "Denitrefying Bed No. 1."

In certain other experiments, to be described presently, a second bed was employed—similar to the above in all respects, except that the broken brick fragments were coarser, viz., from 1½ to ¼ inch diameter This has been called "Denitrefying Bed No. 2."

From this table it is evident that the effects anticipated on theoretical grounds did, in point of fact, occur, and, as regards the destruction of nitrates, to an extent which we had scarcely ventured to anticipate.

Thus, excluding the results of the first experiment (which experiment was made only a few days after starting the denitrefying bed, and evidently before it had got into working order), complete disappearance of nitrates occurred in four of the remaining experiments, and a loss of nearly 90 per cent. in the last. But it should be noted that in this last experiment the rate of flow to the sprinkler had been altered from 260 gallons per 24 hours per square yard of filtering medium to 195, evidently causing (as the table shows) a considerable increase in nitrate production, and it should also be remarked that an unusually small proportion of organic matter (as indicated by the albuminoid ammonia) was present in the septic tank effluent on that occasion.

It will be seen that the purification effected in the denitrefying bed does not fall far short of the purification effected in the same effluent by the sprinkling treatment. The reduction in the amount of free ammonia is, it is true, somewhat less, but that of the albuminoid ammonia is almost identical in the two.

But the most interesting result of these experiments is the remarkable rapidity with which nitrates disappeared in the denitrefying bed, which for that reason was called by the name.

It may be objected that this term implies a difference between an ordinary contact bed and the bed in question. The difference, however, does not lie in the bed itself, but in the method of working it. It is clear from the experiments just described that when this bed is charged with a liquid containing nitrates *plus* easily oxidizable organic matter rapid reduction of the former occurs, with no doubt corresponding oxidation of the latter; while on the other hand, if no nitrates are present in the liquid to start with, the bed may assume an entirely opposite function, and nitrates be actually formed.

SECOND EXPERIMENTS.

The main object of these experiments was to ascertain the conditions under which the maximum reduction of free ammonia could be effected coupled with the maximum destruction of nitrates.

For this purpose various mixtures of tank and sprinkler effluents were employed, and these were treated on denitrefying beds for different periods; while in some of the experiments the sprinkler effluent alone was treated on the denitrefying bed, which latter had previously been in contact with tank effluent and afterwards aerated.

A description of the details of the different experiments made would take up two much space, and for the purpose in view it will be sufficient to give a summary of the results obtained.

This is done in the following table for both series of experiments :—

SUMMARY OF EXPERIMENTS ON DENITREFYING BEDS.

First Experiments.

Number of Experiments Performed.	Parts per 100,000.				Mixture treated in Denitrefying Bed. Volumes of :		Denitrefying Bed Employed.	Working Cycle of Denitrefying Bed.	Percentage Reduction in		Percentage Purification on	
	Nitrogen as Free Ammonia in :		Nitrogen as Nitrate in :									
	Crude Sewage.	Denitrefying Bed Effluent.	Sprinkler Effluent.	Denitrefying Bed Effluent.	Sprinkler Effluent.	Tank Effluent.			Free Ammonia.	Nitrate.	$\frac{1}{3}$ Nitrate Basis.	$\frac{1}{3}$ Nitrate Basis and Solids.
6	3·202*	1·259	1·667	0·178	1	1	No. 1	3 hrs. Contact, 3 hrs. Rest.	60·7	89·4	58·8	67·8

Second Experiments.

4	2·772	0·423	2·317	1·137	2	1	No. 1	3 hrs. Contact, 2 hrs. Rest.	84·5	51·0	70·5	77·8
3	2·873	0·383	2·250	1·441	,,	,,	,, ,,	5 ,, ,, 1 ,, ,,	86·7	36·0	70·0	77·1
8	2·820	0·228	2·240	1·366	,,	,,	,, ,,	4 ,, ,, 2 ,, ,,	91·9	39·0	75·8	81·7
5	2·690	0·406	2·000	0·824	4	3	,, 2	,, ,, ,, ,, ,, ,,	84·9	58·8	74·7	81·1
5	2·690	0·360	2·006	0·920	1	1	,, 1	,, ,, ,, ,, ,, ,,	86·7	54·0	75·3	81·5
5	2·912	0·470	2·284	0·856	,,	,,	,, 2	,, ,, ,, ,, ,, ,,	83·9	62·5	74·1	80·2
3	2·873	0·427	2·250	1·583	Alone	—	,, ,,	5 ,, ,, 1 ,, ,,	85·2	29·7	66·8	74·7
2	2·500	0·350	2·125	1·680	,,	—	,, ,,	2 hrs. Contact, 2 hrs. with Tank Effluent, 2 hrs. Rest.	86·0	21·0	63·4	73·3

* This figure refers to Septic Tank Effluent.

The figures given in the column headed "Percentage reduction in nitrate" have been calculated from the amount of nitrate found in the effluent from the denitrefying bed compared with that present in the effluent from the sprinkler bed, but it should be remarked that the reduction is caused partly by dilution and partly by denitrefication. Thus in the experiments with a mixture of equal volumes of the two effluents, 50 per cent. of the reduction in the nitrates is obviously caused by dilution, and the excess above this figure by denitrefication.

It is somewhat difficult to account for the differences in the results obtained in the two sets of experiments. In the first of these the reduction of nitrates was very considerable, while that of the ammonia was relatively small. On the other hand, in the second series these effects were reversed.

The conditions were, however, by no means the same in the two series of experiments. Thus the sprinkler bed used in the first was only 4 feet high, and the sewage treated per cubic yard of material in the bed 195 gallons in 24 hours; while in the second the bed was 5½ feet high, and the sewage treated at the rate of 161 gallons per cubic yard of material in 24 hours.

The column headed "Percentage purification on ⅓ nitrate basis" requires a word of explanation.

As elsewhere stated (*see* p. 159), it would appear that the *Ulva latissima* absorbs nitrates at a much slower rate than the corresponding quantity of ammonia, and in a given time the seaweed absorbs about three times as much nitrogen when presented to it in the form of ammonia as it does when the nitrogen is in the form of nitrate. Hence it may be argued that the latter has one-third of the potency of the former in encouraging the growth of the seaweed. The figures in the column are calculated from the amount of nitrogen present in the purified effluent as ammonia, *plus* one-third of that in the form of nitrate, contrasted with the amount of nitrogen as ammonia in the original sewage.

The column headed "Percentage on ⅓ nitrate basis *plus* solids" also requires explanation.

The suspended solids present in sewage contain nitrogen, and experiments which are described on pages 135–137 of this report show that when these solids are submerged a portion of the nitrogen is converted into ammonia, and quite possibly after a sufficient length of time the whole of it may be thus evolved.

By treating the sewage first in a septic or sedimenting tank, then on a sprinkling filter, and finally with a denitrefying bed,* the solids are virtually got rid of, and therefore this source of ammonia is also removed.

In the table it is assumed that the original sewage contained 30 parts per 100,000 of suspended solids, and that the latter contained 3 per cent. of nitrogen, and if that is the case the suspended solids in 100,000 parts of the sewage contain 0·9 parts of nitrogen.

The figures in the column in question have been calculated in the same way as those in the column headed "Purification on ⅓ nitrate basis," with the difference that 0·9 has been added to the nitrogen as ammonia in the sewage.

General Review of the Different Methods of Sewage Treatment experimented upon.

In the following table the average results in the several analytical factors are collected for each series of experiments, as well as the degree of purification effected.

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* With due periods for sudsidence (see p. 197).

CONTRAST OF EFFECTS OF DIFFERENT METHODS OF TREATMENT EXPERIMENTED WITH.

Number of Experiments made.	Nature of Sewage to which results refer.	Average Results—Parts per 100,000.				Dissolved Gases. Cubic Centimetres per Litre at N.T.P.			Percentage Purification in:			Percentage of Ammonia in the Sewage converted into Nitrate in Effluent.
		Nitrogen as:			Oxygen Absorbed Test. 4 hrs. at 80° F.							
		Free Ammonia.	Albuminoid Ammonia.	Nitrate.		Carbonic Anhydride.	Oxygen.	Nitrogen.	Free Ammonia.	Albuminoid Ammonia.	Oxygen Absorbed.	
	DOUBLE CONTACT BEDS ONLY.											
12	Screened and Settled	2·13	0·89	0·14	9·01	103·62	0·17	16·89	—	—	—	—
	Effluent	1·04	0·26	0·03	2·62	138·03	0·00	18·66	51	71	71	0
	SEPTIC TANK AND DOUBLE CONTACT BEDS.											
9	Screened and Settled	1·889	0·768	0·230	6·955	—	—	—	—	—	—	
	Effluent	0·236	0·208	0·560	1·555	—	—	—	87	73	78	29
6	Screened and Settled	2·195	0·852	0·092	7·257	99·17	0·28	16·13	—	—	—	—
	Effluent	0·325	0·247	0·740	1·437	101·48	1·50	18·65	85	71	80	34
	SEPTIC TANK AND SPRINKLER.											
6	Septic Tank Effluent	3·078	0·685	—	6·38	—	—	—	—	—	—	—
	Sprinkler "	0·911	0·346	1·555	2·44	44·57	6·53	17·18	70	50	62	50
8	Septic Tank "	2·734	0·590	—	6·33	—	—	—	—	—	—	—
	Sprinkler "	0·337	0·173	1·608	2·04	—	—	—	88	71	68	59
7	Septic Tank "	2·794	0·607	—	6·40	—	—	—	—	—	—	—
	Sprinkler "	0·929	0·201	1·394	2·31	—	—	—	67	67	64	50
5	Screened and Settled	2·990	0·579	—	5·60	—	—	—	—	—	—	—
	Sprinkler Effluent	0·635	0·174	1·563	1·73	—	—	—	79	74	69	49
20	Crude	2·776	—	—	—	—	—	—	—	—	—	—
	Sprinkler Effluent	0·114	—	2·197	—	—	—	—	96	—	—	79
	SEPTIC TANK, SPRINKLER AND DENITREFYING BEDS.											
6	Septic Tank Effluent	3·202	0·683	—	6·610	—	—	—	—	—	—	—
	Denitrefying Bed Effluent	1·259	0·366	0·178	2·885	—	—	—	61	47	57	5
35	Crude	2·912–2·690	—	—	—	—	—	—	—	—	—	—
	Denitrefying Bed Effluent	0·470–0·228	—	1·441–0·824	—	—	—	—	92–84	—	—	66–29

These results, in relation to both the extent of the purification effected and the character of the resulting effluent in each case, may be summarised as follows :—

(1) *Direct treatment of sewage by Double Contact Beds.*

Purification in free ammonia, not good ; in albuminoid ammonia, fair. Production of nitrates, *nil.* Aeration of effluent, *nil.*

(2) *Treatment of sewage by Septic Tank and Double Contact Beds.*

Purification in free ammonia, good ; in albuminoid ammonia, good. Production of nitrates, moderate. Aeration of effluent, slight.

(3) *Treatment of sewage by Septic or Sedimenting Tank and Sprinkling or Continuous Filters.*

Purification in free ammonia, best ; in albuminoid ammonia, fair to good. Production of nitrates, large. Aeration, large.

(4) *Treatment of sewage by Septic or Sedimenting Tank, Sprinkling or Continuous Filters, and finally in a Denitrefying Bed.*

Purification in free ammonia, fair to very good ; in albuminoid ammonia, probably only moderate. Production of nitrates, slight to moderate. Aeration, probably *nil.*

From the above summary we are of the opinion that when a sewage effluent has to be discharged into a fishery stream, and when as a consequence aeration is a factor of prime importance, the best and most rational method of treating the sewage is by septic or sedimenting tank and sprinkler.

But when the effluent is to be discharged into a non-fishery stream, and aeration as a consequence is not of prime importance, the sewage may be treated by septic tank and contact beds, but even in such cases sprinkling treatment may be more advantageous if the watercourse is small, as the nitrate in the effluent is a guard against a possible nuisance, in addition to the dissolved oxygen which it also contains in fair quantity.*

* * * * *

This opportunity may be taken to briefly discuss the merits of the two systems of sewage purification just spoken of, or rather the superiority of the sprinkling filters.

The following appear to be the chief advantages of continuous or sprinkling filters over contact beds :—

(1) Economy in space.

(2) Greater efficiency per unit of area.

(3) Use of a coarser solid or "filling" material than that most advantageously employed in contact beds.

(4) Improbability, if not impossibility, of the filling material becoming clogged or silted up by solids separating from the sewage—if coarse.

(5) Relative cheapness, mainly in consequence of 1, 2 and 3.

Regarding the questions of economy of space and greater efficiency per unit of area when treatment of sewage by a sprinkling filter is contrasted with double contact bed treatment, the following particulars may be given in relation to the experiments described above on these two methods of purification, the sewage being first treated by the septic tank in both cases :—

1. *Contact Bed Treatment.*

Depth of upper bed, 2ft. 6in.
„ lower „ „
Number of fillings per 24 hours, 4.

Rate of working, 187 gallons per square yard per 24 hours for each contact, or 93½ gallons per square yard of surface for complete treatment, or 112 gallons per *cubic* yard of medium.

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* See pp. 195–197.

2. *Sprinkler Treatment.*

In the first series of experiments :—

Depth of Bed, 4 feet.

Rate of working (No. 1, Series 7-14) 150 gallons per cubic yard of medium, or as this bed was 4 feet deep 200 gallons per square yard.

The results of this comparison may also be stated as follows :—

(1) Space required for treating 100 gallons of sewage by double contact on beds 2½ feet deep—1·07 sq. yards.

(2) Space required for treating 100 gallons of sewage by a sprinkler bed 4 feet deep—0·5 sq. yards.

But further than this, suppose the total available fall to be 6 feet, and the contact beds are 3 feet deep, while the sprinkler bed is 6 feet deep, the space required to treat 100 gallons of sewage works out in round numbers to 0·9 square yards for the former, and 0·3 for the latter, or in other words the sprinkler plant would only require one-third as much area as the contact beds, and but little more than one-third of the filling medium.

When the object of the sewage purification scheme is the avoidance of an *ulva* nuisance, the most suitable method would appear to be either treatment by septic (or sedimenting) tank, and double contact beds, or the method of denitrefying the sprinkler effluent just described.

For it will be found that the maximum purification on the "⅕ nitrate basis *plus* solids" was effected by the first of these in which the degree of purification is referred to screened and settled sewage, and amounted to a total of 84 per cent., but in the other similar conducted series where the results are referred to crude sewage, the purification is much the same as that obtained by septic tanks, sprinkler and denitrefying bed, namely about 82 per cent. with the first of these and from 80–82 per cent. in the second.

On first thoughts it might appear that the denitrefying beds would add materially to the cost of the purifying plant, but in point of fact such will not be the case, as the storm beds, which must in any case be installed, can under ordinary weather conditions be used for denitrefying purposes, and if this is done the beds will be kept in an efficient condition for the purification of the dilute sewage passing through them during periods of storm.

Moreover, if this method of treatment is adopted, only part of the sewage will be submitted to the action of sprinkling filters, and therefore the number of the latter required will be much less than if the whole of the sewage were treated by these filters, and in this way an important economy will be effected in the cost of the purifying plant.

Bearing in mind all the circumstances of the case, one of us has recommended this method of treatment as the most suitable and economical for Belfast, where the main object of sewage purification is the prevention of an *ulva* nuisance.

E. A. L.

APPENDIX I.

CHANGES OCCURRING IN THE EFFLUENT FROM A SPRINKLING FILTER WHEN KEPT.

The nature of the changes which occur spontaneously in a nitrated effluent when kept, and more particularly the rate at which such changes occur are important from a practical point of view, and more especially in relation to some of the large manufacturing districts where such effluents are discharged into sluggish streams, the waters of which may not reach the sea for some days.

Have these effluents the power of remaining free from a nuisance, even if undiluted, during the whole of their journey seaward ?

Any laboratory experiments on a question of this kind as a rule only partially reproduce the actual state of affairs, for they are conducted under static conditions, and of necessity ignore the effects of flow and the consequent gaseous interchanges and reactions occurring between the liquid and the bed of the stream on the one hand, and the liquid and the air on the other. However, it seemed worth while to make some laboratory experiments, as they would probably give at least a general indication of the changes likely to occur under actual conditions, as well as an idea of the rate at which those changes would take place, and accordingly the following experiments were performed in collaboration with Mr. R. F. Blake, F.C.S., F.I.C.

In deciding as to the conditions under which they should be made we were guided by the consideration that in all probability the changes at the surface of a body of a nitrated effluent would be different from those occurring in the lower layers, and we therefore decided to perform two sets of experiments, the first under partially anaerobic conditions and the second under complete aerobic conditions. For the first of these a number of Winchester quart bottles were filled to the brim with the effluent, placed in an incubator at 15 deg. C., and after a few hours were then stoppered. For the second the effluent was also placed in Winchester quart bottles, but these were only partly filled, and were shaken with air from time to time. Three series of experiments with different samples of the nitrated effluent were made under partially anaerobic conditions, but the time at our disposal only enabled us to perform one series under aerobic conditions. The results of the different determinations made in all four series are collected in the following table :—

EFFECTS OF KEEPING THE EFFLUENT FROM A SPRINKLING FILTER AT 15°C.

Series.	Date.	Time.	Dissolved Gases in c.c. per Litre at N.T.P.				Parts per 100,000.				
								Nitrogen as :—			
			Carbonic Anhydride.	Oxygen.	Nitrogen.	Total.	Oxygen Absorbed Test (4 hrs. at 80° F.)	Free Ammonia.	Albd. Ammonia.	Nitrite.	Nitrate.
A Out of Contact with Air.	Feb. 22, 1905	Shortly after Collection	50·04	6·55	17·81	74·40	2·27	0·49	0·29	Traces	1·98
	„ 27, „	5 Days „ „	55·61	0·00	18·01	73·62	1·67	0·41	0·22	„	2·10
	Mar. 3, „	9 „ „ „	—	—	18·43	—	—	0·49	0·20	„	1·85
	„ 14, „	20 „ „ „	61·18	0·00	19·74	80·92	—	0·49	0·20	„	1·85
	„ 24, „	30 „ „ „	64·78	0·00	21·85	86·63	—	0·58	0·16	„	1·65
A Exposed to Air.	Feb. 22, „	Shortly after Collection	50 04	6·55	17·81	74·40	2·27	0·49	0·29	„	1·98
	„ 27, „	5 Days „ „	—	—	—	—	2·06	0·44	0·25	„	2·02
	Mar. 14, „	20 „ „ „	—	—	—	—	—	0·18	0·25	?	2·06
	„ 24, „	30 „ „ „	—	—	—	—	—	0·00	0·16	0·00	2·50
B Out of Contact with Air.	Mar. 8, „	Shortly after Collection	39·21	6·84	17·21	63·26	—	0·44	0·19	Traces	2·31
	„ 9, „	24 Hours „ „	40·46	5·13	17·10	62·69	—	—	—	—	—
	„ 13, „	5 Days „ „	44·93	0·08	17·60	62·61	—	—	—	—	—
	„ 15, „	7 „ „ „	—	—	—	—	—	0·36	0·15	—	2·31
	„ 30, „	22 „ „ „	51·04	0·00	19·51	75·55	—	0·48	0·14	—	2·18
C Out of Contact with Air.	Mar. 16, „	Shortly after Collection	44·46	6·20	16·52	67·18	1·25	0·46	0·10	Traces	1·18
	„ 20, „	4 Days „ „	49·38	0·50	16·53	66·41	1·12	—	—	„	1·29
	„ 23, „	7 „ „ „	50·57	0·00	16·86	67·42	0·98	0·33	0·07	„	1·51

These determinations show :—

(1) That the effluent when collected contained an amount of dissolved oxygen approaching the air saturation value.

(2) That on keeping the effluent in a closed vessel this dissolved oxygen gradually disappeared the disappearance being complete in 4 or 5 days.

(3) Most of this oxygen was converted into carbonic anhydride, but a portion also appeared as nitrate.

(4) Later, denitrefication commenced, with the result that more carbon was oxidized to carbonic anhydride, while nitrogen was liberated in the gaseous state.

(5) In addition to these changes, there was a slight but definite increase in free ammonia and a slight decrease in albuminoid ammonia. The two, however, do not completely balance each other, and probably a little nitrogen was lost in the free state.

The following "balance sheet" may be written regarding the first series :—

OUT OF CONTACT WITH AIR—SERIES A.

	Per litre.		Per litre.
Carbonic Anhydride at finish	64·78 c.c.	Carbonic Anhydride equivalent to free oxygen disappearing	6·55 c.c.
„ „ „ start	50·04 „	Carbonic Anhydride equivalent to the loss of nitrate (0·45 per 100,000)	9·00 „
Gain in Carbonic Anhydride	14·74 c.c.		15·55 c.c.
Free Nitrogen at finish...	21·85 c.c.	Free Nitrogen corresponding with the nitrate disappearing	3·60 c.c.
„ start	17·81 „	Free Nitrogen corresponding with the difference between the nitrogen as free and albuminoid ammonia at start and finish	0·32 c.c.
	4·04 c.c.		3·92 c.c.

In the aerobic series (*i.e.*, when the effluent was freely exposed to the air) the changes, so far as they can be followed, are different, but here gasometric analysis is no longer of service, and the usual but coarser methods of analysis can alone be employed.

It will be seen that the nitrates increased in amount, while the free ammonia decreased, and there was also a decrease in the albuminoid ammonia. The gain in nitric nitrogen very nearly corresponds with the loss of ammoniacal nitrogen. The balances stand thus :—

IN CONTACT WITH AIR—SERIES A.

(Parts per 100,000.)

Nitrogen as free ammonia at start - -	0·49	Nitrogen as Nitrate at finish - - -	2·50
Nitrogen as free ammonia at finish - -	0·00	Nitrogen as Nitrate at start - - - -	1·98
Loss of Ammoniacal Nitrogen - - -	0·49	Gain in Nitric Nitrogen - - - -	0·52
Nitrogen as Albuminoid Ammonia at start -	0·29		
Nitrogen as Albuminoid Ammonia at finish -	0·16		
Loss of Albuminoid Nitrogen - - -	0·13		

The results of these experiments indicate that no nuisance can arise from a highly-nitrated sewage effluent, such as is produced by a sprinkling filter, even under the most unfavourable conditions (absence of air).

APPENDIX II.

THE AMOUNT OF SOLIDS PASSING OUT OF THE BED OF A SPRINKLING FILTER AND THEIR COMPOSITION.

It is well known that solids break away continuously from the bed of a sprinkling filter and pass out with the effluent. There is, however, no difficulty in dealing with them, as, owing to their compactness and density, a short period of subsidence suffices for their complete separation from the clear effluent which accompanies them. Still they have to be reckoned with, and the question of their amount is an important one, while that of their composition is also of interest. It was decided to investigate both of these points, and for that purpose the tank into which the effluent passed from one of the experimental sprinklers was carefully cleaned out, and then after a certain working period the deposited sludge was gauged and further examined. The results were as follow :—

Period—October 19th, 1906, to May 13th, 1907.

Total volume of sludge collected	168¾ cubic feet.
Weight of one cubic foot	59 lbs.
Therefore total weight of wet sludge	9,956·25 lbs.

The sludge was black and somewhat offensive.

On analysis it was found to contain—

Water	95·2 per cent.
Dry Solids	4·8 ,,

and the dry solids contained—

Nitrogen	3·6 per cent.
Volatile matters	51·04 ,,
Fixed matters	48·96 ,,

The total weight of dry sludge amounted from the above figures to 477·9 lbs, or 3,345,300 grains.

And the total volume of effluent passing through the tank in the given period was 772,500 gallons.

Therefore each gallon of tank effluent yielded 4·33 grains of dry sludge, equivalent to 6·24 parts of the latter per 100,000 of the former, this 6·24 part containing 0·109 of nitrogen.

SECTION 5.

POLLUTION OF WATER IN RELATION TO ITS EFFECTS ON FISH (*Pisces*).

POLLUTION OF WATER IN RELATION TO ITS EFFECTS ON FISH (*Pisces*).

INTRODUCTORY.

It is beyond question that serious damage has been done to fish by the fouling of the waters which they inhabit by pollution of various kinds, and as might be expected, such damage has been chiefly observed in the streams and rivers of thickly populated districts, where the volume of water is relatively small and the quantity of polluting matters relatively large.

Sewage alone would appear in many cases to be solely responsible for the evil, while in others the waste products from various manufacturing processes are alone concerned. Frequently, however, the damage is apparently done by both kinds of pollution acting together—the stream, river, or estuary of a given district serving unfortunately in too many cases as a "dumping ground" for filth of every description, with fatal effects to its natural denizens. The evil appears to be general and to affect all civilized countries.

In England the condition of the rivers in the manufacturing districts of Yorkshire and Lancashire is too well known to need description, and so also is that of the Thames below London, while in Scotland the Clyde at Glasgow, and in Ireland the Liffey at Dublin have both become proverbial for filthiness. In Germany "The water of most of our mountain streams in these days serves as the motive power of turbines : as the means for washing cotton goods, bleached with chlorine : as the purifier of printed cotton goods after having been treated with phosphoric or hydrochloric acids, as the receptacle for all sorts of chemicals from dye works and chemical establishments. In fact it serves for everything imaginable with the exception of its original purpose, viz., the habitation of fish." *

In Belgium "Our river fisheries, formerly so rich, especially in salmonoids and cray-fish, are in greater danger than those of almost any other country . . . This paradise of fishermen has been well nigh destroyed . . . We may not indulge in the flattering hope of seeing the waters of the Vesdre again rendered sufficiently pure to support fish. They have been too strongly poisoned by the washing of wool and the dyeing establishments and cloth manufactories of Verviers . . . As regards the tributaries of the right bank of the Meuse, the industries which there kill the fish are manufactories of chemicals, sugar refineries and to a less extent distilleries." †

In America in addition to the damage done to fish by pollutions of the ordinary kind, immense destruction appears to have been caused to fish and the fisheries by sawdust.

" The first impression one receives from a hurried survey of the subject of the pollution of the waters from the angler's standpoint is that it begins and ends with sawdust. The reports, the laws, the authorities quoted, the complaints, the litigation, all seem at first to centre in sawdust . . . The net fishermen find their haul nets entangled with sawdust at the bottom. And their nets, too, become clogged with the foul refuse which rot the nets, impedes the handling of the nets and renders more difficult the handling and the saving of the fish, and is at once offensive, unhealthy and expensive. Channels become filled with the accumulating dust, and anchorage grounds broken up. It is on record where twelve feet of water was filled within a few inches of the surface with successive deposits from saw mills. It covers the spawning beds of the fish where it comes down in quantities. The deep holes of the stream become beds of putrid decomposing masses . . . The layers of dust destroy the vegetation in the streams and this destruction of the habitat and food supply of many of the miscroscopic forms which support the young fish, to say nothing of its destructive action on both that food supply and the fish fry directly, is yet unmeasured." ‡

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* Director Haak, Berlin. Monograph U.S. Fish Com. Rep. 1879, p. 675.

† Baron de Selys' Longchamps. U.S. Fish Com. Rep. 1881, p. 815.

‡ Talbott—Report on the Pollution of Rivers to the Game and Fish Protection Association of the district of Columbia, p. 3.

In Sweden considerable injury appears to have been done to fish by "Rafting." "In those parts of Sweden where the fresh water fisheries have been carried on with proper care, they have undergone no important change: have even become more productive in some places. But in most localities, fisheries that were formerly very productive have become unprofitable and have been abandoned in some places. The causes are various. The decrease of fishing areas by sinking and draining of lakes: constantly increasing rafting: saw mills and other mills on account of their dikes refuse, etc. There is no doubt as to the injurious effects of rafting, and it can be made less injurious by removing all the bark from the lumber . . . Rafting injurious in several ways. The refuse gathers on the lake shores, polluting the water to such a degree as to kill the young fish. Schools of fish congregate under large rafts and are killed by turpentine exuding from the lumber. During spawning season, rafting injures fisheries by large masses of lumber driving water high up on shore. The fish deposit their spawn in this water, and when the water recedes, the eggs and sometimes the fry are left high and dry, and perish." *

But as this Report is concerned with the pollution of estuaries and tidal waters only, it is not necessary to discuss the subject of river pollution in detail, and it will be sufficient to indicate a few estuaries in the United Kingdom where it has been proved that pollution has acted injuriously on fish life.

The effects of such pollution have been observed almost entirely in relation to the migratory *salmonidæ*, and more particularly either in interfering with their descent to the sea as smolts or in hindering or actually preventing their ascent to the spawning grounds when they are in the condition of adult fish.

The effects on such fish as inhabit the sea only are more difficult to observe, and as a consequence very little attention has apparently been devoted to the matter.

"The pollution of the Eden has been for some time very bad, and is now worse than ever, owing to the general adoption of the water-closet system in Carlisle, a city of 40,000 inhabitants. The whole of the sewage goes into the river in a crude state, and the river in the summer, when the water is low, is in a most filthy condition. . . . The outfall of the sewer is about half-a-mile, as the crow flies, below the city, and the tide flows up within a mile of that. The whole of the way down to the outlet of the Eden is, in the summer, a mass of about twelve to eighteen inches thick of filthy sludge at the bottom, with gas rising from it † . . . The fishermen fish a long way below the top flow of the tide, and many a time they have to stop fishing in the summer, for in drawing their nets they get a mass of human excreta and all sorts of filth, and the men can hardly be got to work, so bad is it." The evidence went on to show that the spawning beds had been largely destroyed, and that salmon, salmon trout, and hurlings are prevented from ascending the river.

The estuary of the Lune is polluted by the sewage of Lancaster, a town of about 40,000 inhabitants, the whole of the sewage passing into the river without treatment, as well as a good deal of trade waste. Here again a thick and foul deposit is often found in the tideway and fish are prevented from running up the river.‡

The estuary of the Tyne is much polluted, and to a great extent rendered unfit for the existence of salmon, and some of the small tributaries are rendered totally unfit. The bed of the river is coated with deposit which prevents the growth of vegetation. The polluting matters are of various kinds—lead mines and sheep dip in the higher reaches, and in the tideway, chemical works, alkali works, paper mills, mining, and the refuse from various manufactories. No salmon spawn in the South Tyne on account of the lead. The North Tyne is fairly pure and is the main spawning ground for salmon. The pollution of the Tyne has caused a distinct decrease in the yield of salmon, the amount of fish found dead at the head of the tideway and the smolts having largely increased of late years—as many as forty to fifty dead fish being found at a time, sometimes per day, at the head of the tideway, killed mainly by pollutions at Newcastle that are backwatered there.§

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* Prof. A. G. Malmgren. Bull. U.S. Fish Com. 1885, p. 264.
† Roy. Com. on Salmon Fisheries Rep., Part II., p. 25.
‡ *Ibid.* pp. 626, 631, 634.
§ *Ibid.* pp. 189, 190 193, 196.

The estuary of the Dee is polluted by the sewage of Chester and by various trade effluents, including those from galvanising works, paper mills, tar works, artificial manure manufactories, &c. Although the sewage is treated chemically (lime precipitation) before being discharged into the estuary it appears to do damage to the salmon fishery.

"The sewage gets into the river when the tide ebbs, and goes down a certain distance until it is met with the flood tide, and then it comes up and goes down, until the river gets into a filthy state, and dead fish are continually found in the vicinity of this outlet whenever the river is low."

"Fish run up the estuary when they feel the fresh. Some, no doubt, get up the river, but many get into the estuary and tidal portion, perhaps a bit late, and meet the ebb and flow of the stirred-up pollution, and then it must be remembered that in floods people seize the opportunity to run off their pent-up filth. These fish, if not netted, fall back into the sea, and remain there until nature forces them up with a large later run when the water is plentiful.

The Chester Weir, which has no ladder, is an obstruction to fish. They cannot get over in a small fresh. A sixteen-foot tide lets them over. If our salmon get up to this weir and cannot get over it they have a poorish chance of their lives."*

According to Noel Paton† the pollution in these estuaries seems to act in the early months of the year when the rivers are low and the fish not running up rapidly. In other rivers, like the Ribble, Taff, Exe, and Yorkshire rivers, it appears practically to prevent the ascent of adult fish even in the later months when floods dilute the pollution and the gravid fish are striving to reach the spawning beds.

In certain cases the pollution of estuaries has occasioned damage not only to the migratory *salmonidæ* but also to sea fish. Thus "There seems to be no doubt that whatever the cause or causes, the fishing industry in Chichester Harbour occupies at the present time a position of far less importance than was formerly the case . . . So far as I can ascertain, flounder fishing at one time constituted an important branch of the industry in Chichester Harbour, but at the present time few flounders are to be caught there. It appears also that the principal area in which flounders were caught was at the upper end of the Chichester Channel above Dell Quay.

The trouble which formerly arose from the imperfect treatment of the Chichester sewage has been already referred to, and as to the result of my inspection of the site of the former sewage works, I have no doubt but that under previously existing conditions the treatment of the sewage was in fact very imperfect and that the Chichester Corporation were ill-advised in attempting to deal with their sewage under the scheme then in force.

And I have no doubt but that the effluent then discharged into the harbour must under usual conditions have been imperfectly clarified with a resulting deposition of foul sludge in the harbour bed below Appledram. This deposition of sludge in the bed of the stream would have been quite sufficient to drive away from the locality such fish as flounders, which, as the fishermen believe, resorted here for spawning. And it is easy to understand that the destruction of their breeding ground must have made an immense difference to flounder fishing in the harbour.

An additional fact which supports this conclusion is the disappearance of eels from the same area. I understand that with the disappearance of the flounders, eels also have forsaken the upper part of Chichester Channel. I think that it may be accepted as a fact that eels are tolerant of a certain degree of fouling of the bed of a stream which they frequent, but that when fouling has increased beyond a certain point they will absolutely desert the water."‡

Foulerton states that the foul mud is not only derived from the sewage, but also from a decaying sea weed locally called "Cabbage," (which is no doubt *Ulva Latissima*). He also draws attention to the fact that the quantity of fish frequenting the shores of the

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* Roy. Com. on Salmon Fisheries Rep., Part II. Evidence of Major Leadbetter and J. Simpson, pp. 276, 277, 283.

† *Ibid.* Part III. Appendix xxi.

‡ The Pollution of Tidal Fishing Waters by Sewage. A Report to the Local Fisheries Committee of the Sussex Sea Fisheries District on the condition of New Shoreham Harbour and the Tidal Adur, and of Chichester Harbour. By A. G. R. Foulerton.

South Coast has diminished in recent years, and makes the interesting suggestion that this diminution finds a probable explanation in the protection which has been extended to sea fowl in recent years.

"In a partially enclosed water such as Chichester Harbour, it is evident that gulls, cormorants, and other sea fowl must account for an immense number of small fish, a number which probably exceeds in importance the toll levied on fish life by the fishermen.

It is difficult to understand why these fowl which may be regarded as the vermin of the sea shore, should be specially protected any more than rats are protected on land. Sea fish on our coasts already suffer sufficiently from man to render it unwise to afford artificial protection to their natural enemies the sea fowl." *

* * * * * *

The following appear to be the most important ways in which the pollution of water may affect fish :—

1. The polluting substances may absorb the dissolved oxygen of water, eventually causing the death of the fish by asphyxia.

2. The polluting substances may be in themselves of a nature toxic to fish.

3. They may either contain originally a deposit or may eventually give rise to such which may :—

    (*a*) Render the bed of the stream, river, or estuary unsuitable for spawning.
    (*b*) Destroy the natural food supplies of fish.
    (*c*) Cause mechanical injuries.
    (*d*) Lead to clogging of the gills.

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* For particulars regarding outfalls discharging effluents rendering waters unfit or partially unfit for Salmon in England and Wales, see Roy. Com. on Salmon Fisheries Rep., Part III., Section 7, Appendix XXVI., pp. 164–198, and in Scotland *Ibid.* Section 2, Appendix XXIII. and XXIV., pp. 100–125,

EFFECTS OF DE-AERATION.

Although water stands in much the same relation to fish life as air does to that of land animals, there are certain wide differences between the two media to which attention may be drawn. And first there is the difference in diffusibility. A gaseous impurity introduced into air mixes quickly with it even in a closed vessel, in consequence of the rapid movements of the gas particles, while in nature this process is no doubt materially assisted by movements caused by wind. Thus, even in the case of a large city, the composition of the air above it is subject to only slight variations under ordinary conditions. Though in exceptional circumstances, such as those obtaining in a London fog, the variations, while still not very considerable, may be of such a nature as to cause immense inconvenience if not actual injury.

But even in such cases the variations in the amount of oxygen in the air are probably quite insignificant, and the deleterious effects are due not to any deficiency in the amount of that substance, but to the presence of minute quantities of soot, hydrocarbons, sulphurous anhydride, etc., which on the one hand act as a screen in cutting off light, and on the other cause irritation of the lungs and respiratory passages. But in water, not only does the process of diffusion occur with a rapidity of an altogether lower order, but in addition, the velocity of ordinary water currents is much less than that of wind currents, and the mixing effects proportionally smaller. A gale may blow with a velocity of sixty or more miles per hour, but a river or ocean current rarely exceeds one-fifteenth of that rate.

Moreover, as elsewhere stated in this Report,* recent investigations have shown that the aeration of a perfectly still sheet of water proceeds with unexpected tardiness, and only when its surface is disturbed does the air readily penetrate and dissolve, while even under the latter conditions the aerating process is still by no means rapid.

The quantity of dissolved oxygen present in fully aerated water is at ordinary temperatures in round numbers about one-thirtieth of the amount of gaseous oxygen present in the same volume of air, and putrefying liquids, such as sewage, very rapidly absorb that gas. Hence all the dissolved oxygen quickly disappears from water containing sufficient sewage or other putrescible liquid, and the mixture may remain for a considerable length of time in a de-oxygenated condition—not alone because of the slowness with which re-aeration occurs, but also because the mixture may continue to use up the oxygen as fast as it is dissolved from the air. The effect of such a liquid on fish life is of course rapidly fatal, causing death by asphyxiation, while even when the mixture is partly aerated it may still act injuriously, from its containing insufficient oxygen for the normal requirements of fish.

It is of interest to compare in certain directions the respiratory processes of aquatic and terrestrial animals, or to be more accurate, of those which derive their supplies of oxygen from water on the one hand, and from air on the other.

Such a comparison is no doubt impossible in a strictly accurate sense as it would involve a knowledge of the respiratory changes occurring in all animals of both classes, but for the object in view it will be sufficient to compare the respiratory processes of fish and of human beings.

The excretion of carbonic anhydride by the latter varies with the conditions, but if the average amount be taken according to Pettenkofer and Voit, and Vierordt respectively, and it be referred to each kilogram of body weight per hour, the figures are 250 c.c. and 280 c.c. respectively, or 265 c.c. as the mean, and further if the "respiratory quotient" or ratio between the carbonic anhydride exhaled, and the oxygen absorbed, be taken as 0·9, then the oxygen absorbed per hour and per kilogram of body weight amounts to 277 c.c. and 310 c.c. respectively, or, taking the mean of these two figures, to 293 c.c.

According to more recent work by Speck† on the same subject, the hourly absorption of oxygen is 361 c.c. and the evolution of carbonic anhydride 314 (means of 12 experiments), giving a respiratory quotient of 0·87.

Regnard and Jolyet‡ have carefully studied the respiratory changes occurring not only in certain fish, but in other aquatic animals also under normal conditions, and they give the following figures referring to the hourly excretion of carbonic anhydride and hourly absorption of oxygen in c.c. per kilo of body weight, and also the value of the respiratory quotient, for a temperature of 18 C.

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* *See* pp. 56–66.

† Untersuchungen über Sauerstoffverbrauch und Kohlensäureausathmung des Menschen. Cassel, p. 31.

‡ La Vie dans les Eaux, pp. 414–415.

——	CO_2	O_2	$\frac{CO_2}{O_2}$
Actinia	54	55	0·99
Star fish	25·4	31·5	0·80
Oysters	10·7	13·4	0·80
Mussels	9·6	12·4	0·77
Cockles	12·6	15·0	0·84
Cuttle fish	40·0	46·0	0·86
Cray fish (Spiny Lobster)	49·0	55·0	0·89
Lobster	54·0	67·0	0·80
Crab	87·0	107·0	0·81
Shrimps (Crevettes)	108·0	124·0	0·83
Pipe fish (Syngnathes)	74·0	89·0	0·83
Dog fish	45·9	55·0	0·83
Soles	55·0	70·4	0·78
Torpedo (Torpilles)	33·0	54·0	0·61
Conger eel	33·0	43·0	0·76
Red gurnet	67·0	92·0	0·71
Gilt Head (Dorades)	93·0	142·0	0·65
Mullet	109·0	133·0	0·81

Taking from the above table as average figures for fish* the mean between the Conger Eel (of least respiratory activity) and the Gilt Head (of greatest respiratory activity) the hourly excretion of carbonic anhydride is about 63 c.c. and the hourly absorption of oxygen 92, with a respiratory index a little below 0·7.

The average respiratory activity of fish may therefore be taken as from one-third to one-fourth that of human beings, according as the figures for the latter are those which were first given or the later ones by Speck.

The *volume of air* containing the oxygen necessary for the hourly consumption by human beings per kilo of body weight is about 1·4–1·7 litres, while *the volume of water* containing the dissolved oxygen necessary for the hourly consumption by fish per kilo of body weight is about 13 litres (fresh water) or 15 litres (sea water).

It may, however, be pointed out that fish do not appear to be affected by free carbonic anhydride in water to anything like the extent that air-breathing animals are by the same gas when present in the atmosphere.

Thus 5 per cent. by volume of carbonic anhydride in air is certainly beyond the limit which can be tolerated for any length of time without producing serious effects in human beings, but according to Regnard† the proportion of carbonic anhydride may rise gradually to 15–20 per cent. in water before fish are injuriously influenced, and only proves fatal when it reaches 20–30 per cent.‡

As fresh water contains only 0·7 per cent. of oxygen by volume, and sea water 0·6 at 15°C. in round numbers, it is obvious that fish can never cause by their respiratory processes an accumulation of carbonic anhydride in the waters they inhabit inimical to their existence, whereas such accumulation of the gas is rapidly produced in confined spaces by the respiration of human beings, and no doubt by other warm-blooded animals also.

In considering the effects either of toxic substances, or of a diminished oxygen supply on fish, several factors must be taken into consideration, such as the nature of the species, the size (and therefore the age in a given species), and the temperature of the water.

Carp, tench, and, no doubt, eels also, thrive in water containing less dissolved oxygen than is required by trout, and probably other members of the *Salmonidæ* family, and in general poisonous substances in the water affect them less also. Very possibly this may be traced to the sluggish nature of their movements compared with those of the far more active *salmonidæ* with a corresponding lowness of respiratory activity. As to the influence of bulk or volume, according to Quinquand,[*] the respiratory activity diminishes with the weight, but among fish whose weight is less than 500 grams the respiratory activity per unit of body weight is more considerable, no matter what the species may be. Among mammalia the newly-born resist asphyxia more than adults, but among fish the contrary appears to be the case. With regard to the effects of temperature, W. Edwards [†] ascertained that when fish are placed in water deprived of air, the duration of life augmented progressively with the lowering of the temperature of the water from 40° C. to nearly 0° C.

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* This Table does not include *salmonidæ*, the respiratory activity of which is probably higher than of most fish.

† La Vie dans les Eaux, p. 356.

‡ König and Haselhoff found that 10 per cent. by volume in water was harmful to fish (Landw. Jahrbücher, 1897, 26, 75).

Regnard and Jolyet [‡] investigated the amount of oxygen absorbed from water by carp at different temperatures with the following results :—

Temperature.	Volume of oxygen consumed per hour and per kilo of body weight.
2°C.	14·8 c.c.
10 „	37·8 „
30 „	147·8 „

Thus proving the very considerable influence of temperature on the respiratory activity of fish.[§]

The amount of dissolved oxygen in water necessary for fish life has been studied by a number of observers, and chiefly as regards fresh water fish. Perhaps the most important experimental research on the subject is that of Hoppe-Seyler, and Duncan.[¶]

In their experiments the fish were contained in a large pear-shaped glass vessel of about 15 litres capacity, placed on its side, but not quite filled with water, an air space of about 200 c.c. capacity being left. Through openings at each side fitted with corks and tubes, water could be withdrawn from time to time for the analysis of the dissolved gases, or fresh water admitted without disturbing the fish. Also air could be introduced, either of normal composition or with a deficiency of oxygen induced by the respiration of a rabbit under a bell jar, but freed from carbonic anhydride by circulating it through potash tubes before its admission into the vessel containing the fish. The following is a brief summary of the results obtained :—

> 1. With the dissolved oxygen amounting to 3–4 c.c. per litre, tench remained apparently unaffected for from thirteen to twenty-two hours. Hoppe-Seyler, and Duncan compare this proportion of oxygen with an atmosphere containing 8 to 11 volumes per cent. of oxygen, in which warm-blooded animals show no *dyspnœa*.
>
> 2. With the dissolved oxygen reduced to from 0·8 to 1·7 c.c. per litre, trout became either restless and breathing rapidly or were lying on their sides after a period of one and a half to two and a quarter hours. The dissolved oxygen in this case corresponds with an atmosphere containing 2·42 volumes per cent. (? 2 to 5).
>
> 3. With the dissolved oxygen further reduced to from 0·0 to 0·7 c.c. per litre, tench were still alive after from four to twenty hours, though in a bad way. They probably derived oxygen from the upper layers of the water, which were richer in that gas than the lower.
>
> Fully aerated distilled water at a temperature of 15° C. contains in round numbers 7 c.c. of dissolved oxygen per litre, and it will be convenient to speak of this figure as the "air saturation value." Hoppe-Seyler and Duncan's results with fish may therefore be expressed as follows :—
>
> (1) When the dissolved oxygen in water amounts to half the air saturation value, fish (as exemplified by tench) remain practically unaffected for a considerable period.

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[*] Expèriences relatives á la respiration des Poissons, Compt. Rend. lxxvi, 1873, p. 1141.

[†] Memoires sur l'asphyxie. Ann. de Chimie, v. 1817, viii. 1818, x. 1819.

[‡] La Vie dans les Eaux, p. 416.

[§] The effects of temperature on the respiratory activity of *warm blooded* animals is exactly the reverse of those on the respiratory activity of fish and other *cold blooded* animals, that is to say, both the intake of oxygen and the output of carbonic anhydride are *increased* in the former with a *fall* and *decreased* with a *rise* of external temperature.

[¶] Zeitschr. f. Physiol. Chemie, 1893, xvii., pp. 147 and 165.

(2) When the dissolved oxygen is reduced to between one-ninth and one-fourth of the air saturation value, trout are rapidly and seriously affected.

(3) When a further reduction is made so that not more than one-tenth of the oxygen corresponding with the air saturation value remains, sluggish fish such as tench may still exist for some time, but it may be doubted if they could do so in water uniformly of this composition.

König* conducted some experiments on fish with water partly deprived of its dissolved oxygen by a mixture of ferrous sulphate and lime in equivalent quantities, such water being made to gradually replace ordinary aerated water in an open vessel which contained the fish. He found that under these circumstances fish could tolerate water containing from about one-fifth to somewhat less than one-half of the dissolved oxygen corresponding with the air saturation value, without showing any symptoms of injury. He, however, rightly draws attention to the fact that these experiments were conducted in open vessels and were therefore liable to error owing to the possibility of aeration occurring while they were in progress. He considers that fish can tolerate without ill effects water containing 2·2 c.c. of dissolved oxygen per litre or one-third the amount usually present in flowing water.

W. J. Dibdin† kept dace, gudgeon and minnows in a (purified) sewage effluent containing 20–25 per cent. of the air saturation value of dissolved oxygen, but not for any length of time, the fish eventually succumbing and showing a fungoid growth. He considers 50 per cent. of the air saturation equivalent as necessary for fish life. G. D. Thudicum‡ also kept fish in water containing 25–30 per cent. of the dissolved oxygen corresponding with aeration, but states that they only just lived. When, however ,the amount was more than 50 per cent. there was no indication that the fish were even inconvenienced.

Noel Paton§ conducted some experiments on the amount of dissolved oxygen required by small rainbow trout, in connection with an investigation of the effects of the pollution of the Tyne on salmon.

Having first found that a mixture of samples of the waters from the estuary of the Tyne contained no dissolved oxygen after an interval of two days and that fish died rapidly in it, he next showed that the same water when aerated sustained the life of a young trout without further aeration, the dissolved oxygen at the end of this period having been reduced to 2 c.c. per litre : whence he concluded that there was not any chemical substance prejudicial to fish life in the waters of the Tyne estuary.

In his next experiments the fish were placed in ordinary water containing different amounts of dissolved oxygen, and the effects on them observed. From these he concluded that a fall in the dissolved oxygen to below one-third of the normal amount (2 c.c. per litre)|| is prejudicial and generally fatal to young salmonoids—thus confirming the results obtained by Hoppe-Seyler and Duncan.

When the surface of the deoxygenated water was exposed to an atmosphere containing oxygen, the fish seemed to live by constantly coming to the thin layer of more oxygenated water at the surface.¶ Some fish are able to sustain life for a very prolonged period in water containing only minimal traces of dissolved oxygen. Such fish are seen to lie very quietly at the bottom.

It appears to us that a much more extended series of investigations is necessary than any of those which we have summarised above, in order to decide the question as to what standard of dissolved oxygen should be insisted on in relation to fish life.

* * * * * *

In the first place, we are of the opinion that before anything definite can be said on the subject, the investigation for a given species of fish should be extended over a period not merely of hours or days, but rather of weeks or months, and that separate experiments should be made with old and young fish, and that the effects of temperature should also be studied.

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* Die Verunreinigung der Gewässer, vol. ii., pp. 37, 38.

† Roy. Com. on Salmon Fisheries, Rep. 1902, Part II., p. 763.

‡ Roy. Com. on Salmon Fisheries, 1902, Part II., p. 766.

§ Observations on the amount of dissolved oxygen in water required by young *Salmonidæ*. Proc. Roy. Soc. Edinburgh, 1901–1902, 24, Part II., p. 145.

|| The air saturation value for *sea* water at 15° C. is 5·83 c.c. of dissolved oxygen per litre.

¶ The same thing may often be observed in ponds containing fish and long stagnant water.

And again, so far as we can ascertain, no work of the kind has been done in relation to sea water and sea fish, and it should be remembered that the latter have a narrower margin of dissolved oxygen at their disposal than fresh water fish; for whereas the air saturation value (as already stated) is for fresh water at a temperature of 15° C. in round numbers 7 c.c. of dissolved oxygen per litre, for sea water at the same temperature it is only about 6 c.c.

It would also appear to be practically certain that different species of fish have different requirements as regards dissolved oxygen, and that sluggish fish, and more especially such as live on muddy bottoms like the tench, eel, and probably some of the flat fish among the marine species, can tolerate a much lower proportion of dissolved oxygen in the waters they inhabit than swiftly moving and more vigorous species, such as the *salmonidæ*, which probably for that reason only inhabit clear water. Thus each species ought to be individually investigated in relation to respiratory requirements or at least the more typical species. But there is another point which in our opinion should not be lost sight of, namely, that such fish as either inhabit certain estuaries or occasionally pass through them must at times be submitted to the effects of sudden changes from well oxygenated to only slightly oxygenated water, or *vice versa*, while at other times the changes may be of a more gradual character to which the fish may in time accommodate themselves.

Changes of the first kind must occur, one would think, to salmon either running from the open sea up a polluted river, or through a polluted river zone, or back to the open sea from the river, while those of the second kind would be experienced by fish in a polluted estuary during the ebb and flood tide respectively.

The question, therefore, of the effects of rapid changes of the aquatic atmosphere (if the expression may be allowed) on the one hand, and of slow changes in the same, on the other hand, seems worthy of separate investigation.

We had intended to take up this question ourselves, and had decided to experiment with flat fish as representing a sluggish marine form, and with some member of the *salmonidæ* group as representing the more active type.

We proposed submitting individuals of both species to sudden changes in dissolved oxygen in one set of experiments, and to more gradual changes in another. And for the latter purpose it seemed sufficient (at least by way of preliminary trial) to allow the fish to live in a relatively small volume of water, by which means the fish itself would gradually diminish the dissolved oxygen by its respiration, while for reasons already mentioned, the effects of the carbonic anhydride which it exhaled might be ignored.

It was only after performing the two experiments, the results of which are given below, that we discovered that our investigation was illegal without a special licence, and it therefore perforce had to be discontinued.

EXPERIMENT WITH A DAB (*Pleuronectes Limanda*).

Length of Fish, 15 c.m. Weight, 1⅛ oz.

Water in Tank at beginning of Experiment, 78 litres.
" " end " 45 "

Date.	Time.	Temperature of Water.	Dissolved Oxygen per litre.
November 19	10.15 A.M.	8·4° C	5·91
" 19	3.45 P.M.	8·5 "	5·70
" 20	9.45 A.M.	8·8 "	5·58
" 20	6.20 P.M.	9·4 "	4·98
" 21	9.30 A.M.	10·2 "	4·50
" 21	6.0 P.M.	10·4 "	4·08
" 22	2.30 "	10·4 "	3·75
" 23	10.0 A.M.	10·6 "	2·85
" 23	4.30 P.M.	10·7 "	1·80
" 24	9.30 A.M.	10·9 "	1·35
" 24	5.15 P.M.	10·6 "	0·99
" 25	9.40 A.M.	9·3 "	0·43
" 25	6.30 P.M.	9·7 "	0·39

N.B.—The last determination was made when the fish died.

Experiment with a Dab (Pleuronectes Limanda).

Length of Fish, 25 c.m. Weight, 5⅛ oz.

Date.	Time.	Temperature of Water.	Dissolved Oxygen c.c. per litre.
November 26	4.15 P.M.	6·9°C	6·72
„ 27	9.45 A.M.	8·7 „	6·06
„ 28	10.0 „	10·0 „	4·38
„ 29	2.30 P.M.	10·0 „	2·73
„ 30	9.30 A.M.	8·2 „	2·22
December 1	9.30 „	6·7 „	2·16
„ 2	9.30 „	6·2 „	1·92
„ 3	9.45 „	6·8 „	1·74
„ 4	9.30 „	7·2 „	1·56
„ 5	9.45 „	6·4 „	1·50
„ 6	3.0 P.M.	6·1 „	1·47
„ 7	9.30 A.M.	6·0 „	1·38
„ 8	9.45 „	7·0 „	1·35
„ 9	9.30 „	8·2 „	1·32
„ 10	11.0 „	8·6 „	1·29
„ 11	9.30 „	9·6 „	1·23

These experiments show that among flat fish the dab at all events can exist for a considerable time in water containing a very small proportion of oxygen, and it seems improbable from our investigations on the dissolved oxygen contained in some of the chief estuaries and tidal waters of the English and Irish coasts that this species of fish would be seriously affected in any of the fishery districts we have examined.

Notes and Observations.—It is of course well known that salmon and white trout collect in or near to estuaries, and do not venture to ascend certain rivers until a "fresh" or "spate" occurs. In part this may be due to insufficient water being present in the river during dry seasons to enable the fish to pass over the shallow regions and to reach their spawning grounds. But probably an equally cogent reason, at least in certain cases, is that only when the rivers are in flood is the water sufficiently aerated and pure to enable the fish to pass the polluted zone.

In certain polluted rivers, the Liffey for instance, the migratory fish are probably enabled to pass the polluted zone in another way, namely by taking advantage of the layer of sea water brought up by the tide and which lies on the bed of the river or estuary below the polluted fresh water. That this condition of affairs actually exists is shown by the analyses of the Liffey water at different depths (*see* Section 9B, pp. 269–303), and is also demonstrated in a most interesting and convincing manner when the river is in flood and the fresh water coming down is brown in colour. Should a steam boat then pass, the lower layer of sea water is brought to the surface by the action of the propeller and in its wake a track of blue water appears. The effect is most striking and resembles a blue ribbon stretched over a brown ground.*

In our examination of certain of the English estuaries we have been greatly struck by the long reaches of water which exist in which the dissolved oxygen is at a minimum. This is especially the case with the Humber and its tributaries the Ouse and Aire. In the stretch of water between the mouths of the two last-named rivers we found (at the commencement of the ebb tide) only one-third of the air saturation amount of dissolved oxygen, and the conditions higher up these rivers and at a lower state of the tide must have been much worse. It is true, however, that the weather was dry, but even under the most favourable conditions we cannot avoid the impression that the state of these rivers in respect of dissolved oxygen must be seriously prejudicial to the ascent of salmon.

EFFECTS OF SEWAGE POLLUTION.

In attempting to unravel and correctly estimate the effects which may be produced on fish by the pollution of the waters which they inhabit by sewage, much difficulty is experienced, as the action may vary from being actually beneficial, to malevolent in the extreme. A variety of factors come into play, such as the extent of dilution of the polluting matters: idiosyncrasies in the different species of fish in relation to the nature of their food and their resistance to a diminished oxygen supply or to the effect of toxic agents: idiosyncrasies of age in the same species in respect of respiratory activity and general powers of resistance to unfavourable conditions: effects of temperature: and also the difficulty of deciding in cases where sewage pollution is known to be harmful, whether the damage done is due to the effects of toxic substances present in the sewage or merely to removal of the dissolved oxygen.

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* This description is from personal observation.

It would seem that certain species of fish actually feed upon excrementitious material and the following remarkable statement may be quoted:—

"Anyone who has been in Kissingen must have observed the multitude of fish which hover round the openings of the privies on the banks of the Saal and their eagerness to devour the fresh excrement as fast as it falls. And just as the peasant boys and gypsies know how to catch these foul-feeding fish by smearing the bait on their fishing lines with human excrement, so does the heron, if he misses a fish which he strikes at, spread his excrement over the water to entice the fish once more to the surface." [*]

Also regarding the Bass (*Labrus lupus*) and the high esteem in which it was held by the Romans, Couch [†] says:—

"Yet it was the fish preferred by the epicure that ought to have excited disgust, for the favourite station (where it was caught) was indebted for its excellency to the great *cloaca* or principal drain of the city: and as Willoughby observes, it was owing to their being fed with matters that were discharged from it that the fish had obtained the colour and taste which elevated them into reputation. A similar observation has been made in modern times."

König [‡] quotes G. Oesten [§] in relation to the importance of fish culture for sewage farms:

"The effluent from sewage farms contains, it is true, no visible impurities, but on the other hand the organic matter present is capable of further use. On collecting such an effluent in ponds there soon appears a rich growth of plants and lower animals, first bacteria and on adding crustacea these find abundant nourishment in the bacteria, and multiply in an astonishing way. Crustacea are the best nourishment for young trout up to a certain age, for *Coregonen*,[¶] and especially for carp of all ages. If, then, the fish brood is placed in such ponds an extraordinarily rapid development of these is remarked.

In the Berlin Sewage Farm in the Malchow Division six experimental ponds were constructed in the spring of 1890, each of 410 to 820 square metres, in all 3,710 square metres in area, and from ½ to 1 metre deep, provided with the necessary inlets and outlets for the effluent and means for emptying when required. These were stocked with white fish (*Felchen*), [**] ordinary and rainbow trout, carp, and also *Zander* [††] ova, as well as a number of small crustacea, such as *Cyclops* and *Daphnia*.

The crustacea developed so rapidly that their presence was indicated from a distance by the colour of the water, and the fry (*brut*) of choice fish (trout and white fish) were so much developed in October, 1891, they could be served at a banquet. They had reached, in 18 months, an average weight of 250 grams, the carp 500. The *Zander* had developed least. Further prolonged experiments yielded the same favourable results. In order to provide better for the food of the young fish, Prussian carp (*Giebeln*), Rudd (*Plötzen*) and Roach (*Rothaugen*) were placed in each pond. These soon spawned abundantly, so that the *Salmonidæ* had a plentiful supply of small fish to live on.

According to the Report of the Administration for 1897–1898 experiments conducted with "Ostseeschnägelbrut" [‡‡] were also successful. Carp and tench throve excellently, and the carp sold for 152 marks clear profit. In 1896–1897 the carp realised 900 marks.

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[*] C. Jäger, "Die Seele der Landwirtschaft," Leipzig, 1884, p. 51.

[†] Couch. Fishes of the British Isles.

[‡] "Die Verunreinigung der Gewässer," I., p. 337.

[§] G. Oesten Gesundh. M gn., 1899, 22, 117.

[¶] The genus *Coregonus* includes the Grayling, Guinead, Vendace, Pollen and Powan.

[**] Possibly the Guinead only.

[††] *Leucoperca Sandra*. A fish not occurring in the British Isles.

[‡‡] All attempts to find a translation for this word have failed, and indeed the translation of the names of the different species of fish mentioned in the above extract into English has been difficult and in many cases is uncertain, as they either do not appear at all in the dictionaries, or if so, are often translated differently. Moreover, on consulting Germans, thoroughly familiar with the English language, we found that they were in ignorance even of the German names for most of the fish.

For the success of the fish pond industry good aeration and exposure of the water to sunlight are essentials. A boggy or spongy pond bottom is unsuitable as it does not encourage the development of those lower animals which serve as fish food."

Oesten proposes to collect the sewage farm effluent in suitable ponds, and to inoculate it with the proper organisms, serving eventually for fish food. Next, to pass it into a crustacean pond, where the bacteria are devoured by the crustaceans, and the latter increase and multiply. Lastly, to pass it into the fish-breeding ponds.*

The suitability of a sewage farm effluent for fish life is, according to Oesten, the best criterion of purification, and he proposes the following standard:—

"The effluent from sewage flowing into open water must be of such nature that fish live and thrive in it, and as a control apparatus a fish pond fed by such effluent."

König points out, however, that fish might live in water containing a high proportion of chlorides and sulphates or small quantities of colouring matters, while such water would be unsuitable for farming or manufacturing purposes.

* * * * * *

Anyone who has carefully studied the seaside must have noticed the abundant flora and fauna near the mouths of small sewers, and particularly such as lead from cesspools. Mussels, shrimps, annelids, and other small animals are plentiful, while the *ulva latissima* and other green sea weeds grow luxuriantly.

It cannot, therefore, be doubted that under certain circumstances the discharge of sewage or of sewage effluents into water, supplies fish, either directly or indirectly, with food, and does not act deleteriously on them.†

It is probable, if not indeed certain, that this is only the case when the dilution of the sewage with fresh or sea water is sufficiently large to ensure a sufficiently large residuum of dissolved oxygen.

When, however, the volume of the sewage is relatively considerable, compared with that of the diluting medium, a totally different set of conditions may arise.

The dissolved oxygen may almost or even entirely disappear, and in the latter case, sulphuretted hydrogen, so deadly to fish life, may be generated, The stream or estuary may as a consequence become actually foul, the waters turbid or even inky from the production of ferrous sulphide, and the bed coated with a black and evil-smelling deposit. Under such circumstances fish life becomes impossible, the spawning beds are destroyed, aquatic plants—so important as oxygenators of stagnant water—disappear, and the whole locality becomes a festering eyesore.

This is no fancy picture, as precisely the conditions described are still to be found in the Clyde at Glasgow, the river actually effervescing at low water from the escape of foul gases from its bed, while the Ship Canal at Manchester is in a similar filthy condition, and the Liffey at Dublin is nearly as bad.

As regards the actual effects of sewage pollution in varying proportions on fish life, probably the most important and extensive series of experiments were made by Weigelt,‡ who collected for the purpose the wash water, kitchen water, etc., from his own household and diluted a portion with ordinary water to bring it up to a standard of a water supply of 110 litres per head per day, while another portion was mixed with urine, fæces and ordinary water to correspond with a water supply of 150 litres per head per day. Both liquids were allowed to ferment for eight days (in August) before being employed for the experiments on fish.

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* This scheme Oesten has patented. D.R.P. 101706.

† *See* Herdman's evidence before this Commission, Interim Report, Vol. II., p. 485.

"Shell fish certainly feed upon sewage. Shrimps feed upon sewage; many of the minuter things which form the food of the large ones feed upon sewage, such as the little animals in the sea called *Copepoda*, small crustacea, microscopic things which are present in enormous amount, which are more important than anything else in the sea as food for fishes. They feed largely on sewage and act really as scavengers and convert sewage into what one may call good food for the fish."

Also McIntosh (Roy. Com. Salmon Fisheries, 22377–8) "We know that the placing of new sewage outlets in the sea has a remarkable influence upon the sea trout. I may instance one case, namely the placing of a sewage outlet, which was a new thing in the sea at St. Andrews. The men went with nets a year or two afterwards perhaps and caught large numbers of sea trout there, and young salmonoids around the exit of the sewage pipe. They were never known to be found in such numbers at that part previously," from which he came to the conclusion that sewage attracted small forms of life such as shrimps which the fish fed upon.

‡ Landw. Versuchstationen, 1882, 27, 315. Archiv. f. Hygiene, 1885, 3. 70.

Some of these experiments were made in large glass cylinders containing five litres of the mixture, the time being noted which elapsed after introduction of the fish until it lay permanently on its side, this time being called by Weigelt the " Resistance Period."

The fish experimented on were trout, salmon, tench, " bastard salmon," Californian salmon, salmon trout, and also the ova of trout and grayling.

With both the housewater and the sewage, trout were nearly instantaneously brought to the resistance limit, and with a dilution of four times with ordinary water the Californian salmon and salmon trout remained unharmed for two hours. With a dilution of one part of the sewage to five of water small Californian salmon were killed in thirteen hours, and salmon trout in eighteen hours. Similar dilution of the housewater gave a mixture which did not apparently affect the same species of fish in eighteen hours, but they died a few days later, having been placed in the interval in running water.

Further experiments were tried with dilutions 1 : 10, 1 : 20, 1 : 40, and even in the highest of these dilutions (sewage) Californian salmon and salmon trout died in three to four days. But on the other hand those in the diluted house water were not apparently affected. Nevertheless in the dilution 1 : 10 of the house water one of the fish died after some days when placed in fresh water while the growth of the others was visibly affected, and after four weeks they were easily distinguished from similar fish which had not been experimented upon by their darker colour.

Notes and Observations.—So far as we are aware, no work has been done on the effects of sewage in a fully aerated mixture with water,* and Weigelt's results were possibly and indeed probably due to the effects of de-aeration and not to the presence of toxic substances.

The only estuary which has come under our notice, where sewage is distinctly in evidence is that of the Eden below Carlisle. We can fully endorse the remarks made by a witness before the Royal Commission on Salmon Fisheries, quoted on page 202. The bed of the river for some miles below the tidal limit is coated with sewage sludge, and a net drawn across the river during our visit brought up a thick deposit of foul matters.

We were informed that salmon caught in the Eden have a distinct taste. Whether this is the case or not we do not know from personal experience, but owing to their disagreeable flavour we were unable to eat some " hurling†" which we saw caught in the estuary and which looked fine fresh run fish.

EFFECTS OF CERTAIN SPECIFIC IMPURITIES.

Suspended Solids.—These, according to the authorities on the subject, may act in several different ways on fish, such as (*a*) in certain cases by causing mechanical injury ; (*b*) by clogging the gills ; (*c*) by imparting poisonous properties to the water.

Leuckart‡ investigated the effects of water containing a sediment of manganese peroxide, but according to König his remarks apply generally to waters contaminated with suspended particles.

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* With the exception of Noel Paton's experiment with the waters from the Tyne Estuary alluded to on p. 208.

† Salmon trout ?

‡ Ein Gutachten über die Verunreinigung von Fisch und c. Wässern," quoted by J. König in " Die Verunreinigung der Gewässer," 1, p. 82.

The manganese sediment referred to by Leuckart contained quartz particles and clay. The sharp edges of the former wound the skin of fish, particularly the eyes and gills, and the effects, small at first, may become considerable later. Siebold informed Leuckart that he had seen fish with their eyes quite destroyed by quartz particles, so that the black pigment protruded and the gills showed abundant extraversations. These fish had been in a box, which, during a continued period of rain, had been submitted for some time to the action of a sediment containing quartz particles. Indirectly, sediments affect fish by covering the bed of a stream and closing up their resting places, preventing or destroying vegetation, and thus depriving the fish of an important souice of oxygen, and also of the minute animals feeding on vegetation, and in their turn serving as food for fish.

Sediments also affect fish ova, by actually tearing the membranes if particles of quartz are present, or by hindering the admission of oxygen (fish often depositing their ova near water plants to secure proper oxygenation). The ova may become covered with a layer of sediment which hinders diffusion.

Leuckart experimented with frogs' spawn and fish ova (white fish) covered with a layer of manganese peroxide ½ mm. and less thick, and found that they were destroyed—though the conditions were otherwise favourable. Busch showed that this was also the case with ordinary water sediments.* Leuchart also showed that the sediment acts injuriously by cutting off the light, which is necessary for normal development. The layer of sediment surrounding the ova also prevents the water from acting as before. Thus the effects of sediments on fish ova are various.

Finally sediments may cover the natural spawning grounds and render them unsuitable.

Certain sediments act injuriously on fish when present in minute quantities, and may be considered as specific fish poisons, according to Weigelt, and notably the oxides (hydrates ?) of iron and aluminium—·01 to ·02 grams per litre of the former and ·0038 to ·007 of the latter acting injuriously.

König and Haselhoff † found that alum acts in a remarkably acute way on trout—0·1 gram per litre of water proving harmful even after a short time, whereas tench were not affected by 1·0 gram per litre even after sixteen to eighteen hours. For gold fish they found the limit of safety somewhat higher than Weigelt's figure, namely, about 0·3 gram potash alum per litre or 0·0171 of aluminium, and they remark that the difference was probably due to the differences in the quantity of suspended alumina in the water, as without doubt the action of metallic hydrates on fish is mechanical and causes clogging of the gills.

They found that 0·23 grams of chrome alum per litre at 15°C. did affect gold fish, whereas Weigelt found 0·20 at 9°C. to be without action on a large trout. Here again the difference was due to the amount of precipitated hydrate. Experimenting with fish ova, Weigelt found that potash alum was harmful. Only 0·9 per cent. hatched out in a solution containing 0·1 gram per litre, whereas 51·5 per cent. hatched out in water without the alum. Nitsche Tharaud obtained similar results.

Notes and Observations on Sediments.—During our tour of inspection and investigation of some of the chief estuaries on the English coast we were much struck by the extraordinary amount of suspended matters present in some river waters. This was specially remarkable in the Usk (Monmouthshire), the Thames, and the Humber and its tributaries, the Ouse and Aire. In the Usk, which is notable for its salmon fisheries, a tumbler full of water collected in mid stream several miles above Newport deposited sediment to such an extent that its height was at least $\frac{1}{10}$ that of the water. While the "warp," as the sediment is called in the Humber, is, we believe, utilized as a manure for the low-lying lands by occasionally flooding them and allowing the suspended matters to deposit on their surface.

How salmon find their way up the long muddy reaches of the Usk, the Humber, and its tributaries and the upper reaches of the estuary of the Severn, which are also full of sediment we must leave the naturalists to explain, but it appears to us impossible that the fish can be guided by the sense of sight during their journey, as a few feet below the surface they must be almost if not quite in darkness. It is, however, obvious that the mud or silt found in these rivers cannot be inimical to fish, or at all events to salmon.

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* Molai—Die rationelle Zucht der Süsswässer fische. Wien 1864, p. 164–172.

† König and Hasehoff.

Coal Washings. In some of the rivers of South Wales such as the Rhymney, the Taff and Ogmore, and also in the Tyne and Wear, extensive damage appears to have been done to the fish and fisheries by coal washings. König found in 1 litre of coal washings :

	grams.
Coal dust	7·596
Sand and clay	5·563
Matters in solution	0·609
Common salt	0·124

The solid particles no doubt act mechanically both on the fish and spawning beds as already described.*

The toxic constituents in solution are derived chiefly from the iron pyrites present in the coal, which by oxidation is converted into sulphuric acid and ferrous sulphate and the latter eventually into ferric hydrate.

Clay Washings.—These occur in certain of the English Rivers such as the Camel, the Plym and the Teign, and damage the spawning beds, and it is stated fish also, inducing disease of the gills.

Washings from Lead Mines.—These are found in the Wear, Towey, Derwent, Wye, Tyne, etc., and act no doubt mainly mechanically, by covering the spawning beds, destroying vegetation, etc.

Washings from Slate Mines occur in the Seiont and render the river partially unfit for salmon.

Tin, Copper, and various Metallic Mines.—In the Tamar and Plym and their tributaries the water either pumped from the mines (tin, copper and arsenic) or used in dressing the ores has damaged both the spawning grounds and the fish, while in the Teign the washings from a tin mine have rendered that part of the river wholly unfit for salmon, and a similar remark applies to the Mawddach, which is polluted partly by water employed in the Glasdic copper mines and partly by silt from the British Gold Fields Company.

In these cases the injury done to the fish is no doubt partly mechanical from the solid particles and partly of a true toxic character from the presence of soluble impurities, the latter being sulphuric acid and ferrous sulphate, copper sulphate and possibly arsenical compounds produced by the oxidation of the iron, copper or arsenical pyrites.

Alkali Waste.—The toxic constituent from alkali waste appears to be calcium sulphide.† If the amount is 16–39 milligrams per litre, and the water soon renewed the asphyxia is only partial, and the fish can be saved. Above these quantities the fish die in a short time. Fish can tolerate large quantities of calcium hyposulphite and manganese chloride.

Weigelt investigated the effects of sodium sulphide on fish and found that the action varied with the temperature. At 20° C., with 100 milligrams per litre, the resistance period for a tench was one hour and twenty minutes, and with 50 milligrammes per litre two hours and twenty-six minutes. The first fish died when removed to fresh water in six days, while the second recovered. At a temperature of 8° C. with 0·1 per cent. a tench lay on its side after nine hours and forty-five minutes.

Tanneries.—The effluents from tanneries may contain lime, tannin, chromic acid, mineral acids, and sometimes arsenic. From 20–30 milligrams of lime per litre causes fish to become sick ; 70–150, death in thirteen to twenty-six minutes.

Weigelt found that 50 to 100 milligrams of tannin per litre did not act poisonously on trout and tench, but ten grams per litre did.

Tannery effluents soon become foul, and rapidly absorb oxygen from water.

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* In the Ogmore and Taff this deposit is described by witnesses before the Roy. Com. on Salmon Fisheries as being inches deep.

† Grandeau : La soudvère de Dieuze &c , Paris, 1872.

Gas Works and Tar Water.—The effluent from gas works in addition to absorbing oxygen rapidly, contains definitely toxic substances, such as cyanides, sulphocyanides, phenol, etc. As regards tar, Weigelt found that 0·2–10·0 grams in 1 litre of water acted injuriously on tench. Kämmerer experimented with gasometer water, and found that small quantities were toxic to fish.*

Paper Factories.—The caustic soda boilings of the materials used in paper-making absorb oxygen rapidly, and are very prone to undergo putrefactive changes. Further, any chemicals from such works exercise their own specific influence.

Flax Retting.—The water used for this purpose becomes intensely putrid and emits a very foul odour. Fausto Sestini found per litre of retting water :—

Soluble Matters. grams.	Nitrogen in the same. grams.	Organic Acids calculated as Butyric Acid. grams.
6·140	0·663	0·044

Serious destruction of fish occurs frequently when this water is turned into streams.

Common Salt.—Fresh water fish can tolerate water of considerable salinity ; thus genuine fresh-water fish are found in the Baltic near Rugen, such as perch and zander.†

The influence of the salts of sea water on fresh-water fish has been studied by Varigny and Paul Berth ‡ while Bert also made some highly important and interesting experiments on the acclimatisation of various fresh water species to salt water.

He very gradually added sea water to fresh water,in which where fish, tadpoles, fresh water crustacea and confervoid growths, and succeeded in getting them into a condition of half acclimatisation, *i.e.*, they lived in the mixture, but others soon perished when placed in it without the acclimatisation process. Crustacea reached a condition of complete acclimatisation in a gradually made mixture of one-half fresh and one-half sea water. These were killed when returned to the fresh water medium.

Bert made the further highly interesting observation that if the mixture of fresh and salt water was made rapidly (two of the former to one of the latter), *i,e.*, in a few days *Daphnia* died, but their ova survived, and developed. Here then an acclimatisation, not of the individual but of the species, occurred. The only differences to be remarked in this race compared with their parents being their size, and also that they died in fresh water. Infusoria (*Paramecia, Coltpoda, Vorticella*) *Diatomaceæ* and *Conferva* tolerated a much salter mixture than fish and crustacea. In general, a salt content of water corresponding with a mixture of two parts fresh to seven parts of sea water kills fresh-water fish, but they can be acclimatised easily to a mixture of equal parts of the two, or a slight excess of sea water over that amount, but acclimatisation above this is very difficult. The rate at which the salinity can be raised during the acclimatisation process is about 0·1 grams salt per day.

The rapidly fatal effect produced on a fresh-water fish when suddenly placed in sea-water, or *vice versa* when a marine species is placed in fresh water, is no doubt due to osmotic phenomena. This is indeed proved by the loss in weight which the fish experiences in the first case, and gain in weight in the second.§

Certain fish—eels for example—are protected from this osmotic effect by a coating of mucus, and as a consequence can tolerate a sudden change in the salinity of the water. Should, however, this mucus be accidentally removed, say, by handling, immediately before the change, the fish succumbs.

We conclude this section by giving a table showing the effects of certain chemical substances on fish.

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* Dinglers Polytec. Journ., 1875, p. 88.

† König die Verunreinigung der Gewässer.

‡ Compt. Rend. 97. 55, and 131.

§ A frog when plunged into sea-water loses a fifth of its weight. It can be killed by simply immersing one of its legs in sea-water.

EFFECTS OF CERTAIN CHEMICAL SUBSTANCES ON FISH.

Substance.	Quantity in Grams per Litre.	Effects on Fish.	Authority.
Alum	0·100	Harmful to trout after a short time.	König and Haselhoff.
,,	1·000	Not harmful to tench after 16 to 18 hours.	
Ammonium sulphocyanide	0·100	No action on trout after 1 hour.	Weigelt.
Arsenious anhydride	0·100	Not poisonous to tench in 17 hours, or to trout in 2 hours at 8–9°C.	,,
,, ,,	0·0272	Tench and carp not visibly affected during 3 days.	König and Haselhoff.
Bleaching powder	0·005	Causes death of tench at 6.14°C.	
,, ,	0·008	Kills salmon and trout at 6-14°C.	
Calcium chloride	6·0–7·0	Limit of safety for fish.	König and Haselhoff
,, ,,	5·0	,, ,, ,,	Weigelt.
,, ,,	2·40	Toxic for fish.	Richtet.
,, sulphide	0·016–0·039	Fish sicken but they recover in fresh water. With larger amounts fish die.	Grandeau.
Chrome alum	0·230	Gold fish affected at 15°C.	König and Haselhoff.
,, ,,	0·200	Without action on a large trout.	Weigelt.
Copper sulphate	1·0	Brings a trout on its side in 2 minutes at 7·5°C.	,,
,, ,,	0·1	Brings a trout on its side in 7 minutes at 7.5° C.	,,
,, ,,	0·010	Fatal to fish.	Penny and Adams.
,, ,,	0·010	Causes death after long exposure with clogging of the gills by a slimy deposit.	König.
Ferric chloride	1·0	Decided action on trout. Tench not so susceptible.	
,, ,,	0·125	Acts as a poison on fish after 24 hours.	
Ferrous sulphate	0·050	Not permanently dangerous to trout.	Weigelt.
,, ,,	0·025–0·015	The limits for fish.	König and Haselhoff.
Hydrochloric acid	0·100	Decided action on trout. Tench not so susceptible.	
Lime	0·140	Fatal to fish.	Penny and Adams.
,,	0·150–0·070	Caused death in 13–16 minutes.	Weigelt.
,,	0·030	Caused sickening.	,,
,,	0·020	Dangerous to fish.	König.
Magnesium chloride	6·0–7·0	Limits of safety for fish.	König and Haselhoff.
,, ,,	1·5	Toxic to fish after 24 hours.	Richtet.
Manganese ,,	1·000	Decided action on trout, tench not so susceptible.	
,, ,,	0·300	Acts as a poison on fish after 24 hours.	
Mercuric ,,	0·05–0·10	Kills trout and tench in 29 minutes.	König and Haselhoff.
Phenol	0·05–0·01	The limits for tench.	,, ,, ,,
,,	0·05–0·01	,, ,, trout.	,, ,, ,,
,,	0·014	Fatal to fish (a nerve poison).	Penny and Adams.
Picricacid	0·050	Carp killed immediately.	König and Haselhoff.
,,	0·020	No action on carp after 10 days.	
Potassium Cyanide	0·005–0·010	Nearly kills trout and tench, but the fish recover after the resistance period is reached if they are placed in fresh water.	,, ,, ,, Weigelt.
,, Chromate	0·200	Did not harm trout after 1 hour.	König and Haselhoff.
,, ferrocyanide	1·000	,, ,, ,,	,, ,, ,,
Sodium arseniate	0·05–0·10	Limit of safety for fish.	Weigelt.
,, ,,			
,, sulphide	1·00	Resistance period for tench, 9 hours 45 minutes at 8°C.	,,
,, ,,	0·10	Resistance period for tench, 1 hour 20 minutes at 20°C.	,,
,, ,,	0·050	Resistance period, for tench, 2 hours 26 minutes at 20°C.	,,
,, carbonate	5·0–10·0	Resistance period for trout, 3 hours at 6–12°C.	,,
,, ,,	2·4	Tench and carp not affected in 4 days at 9–15°C.	König.
,, ,,	0·05–0·10	A large trout died in 9 hours, A tench not affected in 14 hours at 6–12°C.	

EFFECTS OF CERTAIN CHEMICAL SUBSTANCES ON FISH—*cont.*

Substance.	Quantity in Grams per litre.	Effects on Fish.	Authority.
Sodium chloride	24·0	Poisonous amount for fish.	Richtet.
,, ,,	10·	Kills tench in 5 hours at 50 P,C..	Grandeau.
,, ,,	6·0–20·0	Does not affect trout and tench in 21 hours.	Weigelt.
,, ,,	5·876	Carp found in a healthy condition in water containing this amount.	König.
,, ,,	13·332	No damage to a carp 100 grams in weight in 6 days	König and Haselhoff.
,, ,,	15·184	A carp 150 grams in weight died in 40 hours.	,, ,,
Sulphurous anhydride	0·0005	A large trout lay on its side in 3 minutes.	
Sulphuric acid	0·100	Limit for trout, 2–6 hours.	Weigelt.
,, ,,	0·035–0·050	Limit for carp and tench.	König.
,, ,,	0·020	Fatal to fish.	Penny and Adams.
Tannin	10·000	Injurious to fish.	Weigelt.
,,	0·100	Did not act injuriously on trout or tench.	,,
Zinc sulphate	0·140	Poisonous to fish after 2½ hours.	Raümur.
,, ,,	0·0084	,, ,, ,, 48 ,,	Richtet.
,, ,,	0·110	The limit for a tench of 70 grams weight.	König and Haselhoff.
EFFECTS OF CERTAIN CHEMICAL SUBSTANCES ON FISH OVA.			
Alum (potash)	0·100	Only 9 per cent. fructified while 51·5 per cent. fructified in pure water.	Weigelt.
Copper sulphate	0·100	Only 9 per cent. fructified while 51·5 per cent. fructified in pure water.	,,
Ferrous sulphate	0·100	Only 40·3 per cent. fructified, while 51·5 per cent. fructified in pure water.	,,
,, ,,	,,	Damages ova.	Nitsche Tharaud.
Hydrochloric acid	1·000	99 per cent. dead in one day.	
Sodium carbonate	2·000	100 per cent. fructified after 30 days' contact.	,, ,,
Sulphuric acid	0·500	Only 2 per cent. fructified.	Weigelt.

E. A. L.

SECTION 6.

METHODS EMPLOYED IN FIELD WORK.

METHODS.

(1) DETERMINATION OF DISSOLVED OXYGEN.

Volumetric Process for Determining Dissolved Oxygen.

For all the "field work" described in this Report we have employed the volumetric process originally devised by one of us in association with another chemist and described in the Proceedings of the Royal Dublin Society.* The method has been tested by us again and again by a comparison of the results with those obtained from the same samples of water by boiling out the dissolved gases *in vacuo* and submitting them to gasometric analysis, and under all ordinary conditions the method has been found to be very accurate.

Under exceptional circumstances, however, it ceases to give accurate results.

A full account of the process has been already submitted to the Commission with the tests of its accuracy, etc., but as this is a separate Report we think that an account should be given of the working details of the method.

The principle of absorbing the dissolved oxygen in a water by ferrous sulphate and an alkali with subsequent determination of the unoxidised ferrous salt in the acidulated mixture by standard permanganate is an old one, and was first employed, we believe, by Mohr.

The method as carried out according to his directions is, however, open to several sources of error, of which, as we have proved, the use of permanganate as oxidising agent may, in certain cases, be one of the most serious. It also has the disadvantage of requiring the use of an inactive gas during part of the process.

While making use of the principle of this method to the extent that the dissolved oxygen in a water is absorbed by a ferrous salt plus an alkali (*i.e.*, by ferrous hydrate), and the excess of ferrous salt determined subsequently in the acidulated mixture by titration with an oxidising agent, we have sought to eliminate the various sources of error incidental to Mohr's process, and to avoid the use of an inactive gas during any part of the operations.

The whole process is simple, and one which a person of ordinary intelligence, but without any special chemical training, can be early taught to perform. Stated briefly, it consists in adding a definite quantity of ferrous sulphate solution to a measured volume of the water under examination, and then excess of ammonia in a vessel which becomes entirely filled with the mixture and is eventually closed previous to mixing the three during the period necessary for the absorption of the dissolved oxygen. Sulphuric acid is then added in excess in such a way that no air can gain admission during the operation, after which the mixture is transferred to an open vessel, and there titrated either with standard permanganate or bichromate, according to the class of water under examination.

In order to eliminate the possible error due to easily oxidisable substances which may be present in the water, a blank experiment is made in an open vessel, in which the same volumes of the water, the ferrous sulphate solution and sulphuric acid are placed, and the titration performed with the same standard solution of oxidising agent. The details of the method are as follow :—

Standard Solutions.

(1) *Ferrous Sulphate.*—12½ grams of the pure crystallised salt are weighed out on a rough balance, transferred to a 250 c.c. flask, dissolved in distilled water, 2–3 c.c. of pure

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* Letts and Blake. Proceedings Roy. Dublin Soc., Vol. IX. (N.S.), Part IV., No. 33.

sulphuric acid added, and the mixture diluted with distilled water until it occupies 250 c.c. Theoretically 12·444 grammes of the ferrous salt are required for a solution each cubic centimetre of which is equivalent to 1 cubic centimetre of oxygen at N.T.P., but nothing is gained by preparing a solution of exactly this strength.*

(2) *Standard Permanganate.*—The most convenient solution is of such strength that 1 cubic centimetre is equivalent to 1 cubic centimetre of oxygen at N.T.P.; and such a solution is obtained by dissolving 5·638 grammes of the pure crystallised potassium salt in 1 litre of distilled water.†

For the estimation of the dissolved oxygen in distilled water itself, or in ordinary (fresh) water, a solution of one-tenth this strength may be used; but for all practical purposes the stronger solution will be found to give sufficiently accurate results, especially if a narrow burette of 10 c.c. capacity is employed. The stronger solution keeps well (in the dark), but the weaker one should be prepared freshly from the former for each series of experiments.

(3) *Standard Bichromate,* of a strength corresponding with that of the permanganate, may be employed instead of the latter; and in the case of sewage effluents and in that of sea water is undoubtedly to be preferred. Of course, in using bichromate, potassium ferricyanide must be employed as indicator; and as the ferrous sulphate solution is highly diluted by the water under examination, the strong bichromate can alone be employed with advantage. This is prepared by dissolving 8·7906 grammes of the pure crystallised potassium salt in 1 litre of distilled water, each cubic centimetre of such a solution corresponding with 1 cubic centimetre of oxygen at N.T.P.

(4) *Sulphuric Acid.*—A mixture of equal volumes of the strong acid and water is employed. But we have also used a mixture of 3 volumes of the strong acid and 1 volume of water.

Absorbing Vessel.‡—The vessel in which the water under examination is mixed with the ferrous sulphate and ammonia, and in which, too, the mixture is afterwards acidulated with sulphuric acid, was in our first experiments an ordinary separating vessel of the shape and capacity shown in the diagram (Fig. 1). The exact dimensions, however, are of no consequence, provided that the vessel holds about $\frac{1}{3}$ litre of water and that the tube forming its lower extremity is wide enough to contain the quantity of sulphuric acid required to acidulate the ammoniacal mixture before titration.

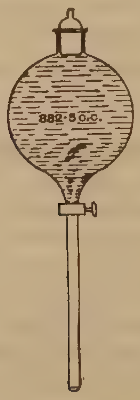

Fig. 1.

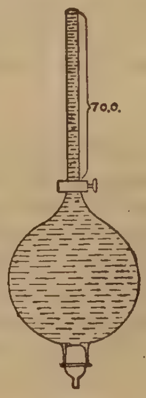

Fig. 2.

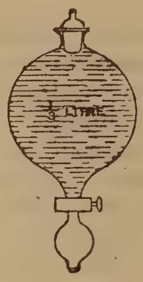

Fig. 3.

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* The solution keeps fairly well, but unless a series of determinations is made with it at short intervals, it is advisable to re-standardise it on each occasion when it is used. The following figures will give an idea of the rate at which it becomes oxidised when kept in a stoppered bottle :—

When made 5 c.c. required 5·06 standard bichromate.
After 5 days „ „ 5·01 „ „
„ 11 „ „ „ 4·92 „ „

† A decinormal solution of the permanganate (3·164 grammes per litre) is also of a suitable strength for the titrations, 1 c.c. of this solution corresponding with 0·56 c.c. of oxygen at N.T.P.

‡ As an ordinary separating funnel is somewhat unwieldy for the purpose of these determinations, owing to the length of the tube, Messrs. Baird and Tatlock, of London, have constructed for us a special form of apparatus shown in the diagram (Fig. 3), which is very handy and convenient, and contains exactly $\frac{1}{3}$ litre. The same firm also supplies the whole of the necessary apparatus and reagents for the determinations, packed in a box of portable form.

The Process.—The separating vessel is filled to the brim with the water under examination, and for this purpose we have always employed a glass syphon tube, one limb of which is dipped almost to the bottom of a Winchester quart bottle (filled originally to the brim and then stoppered) containing the sample of water, while the other and longer limb is connected with a piece of india-rubber tube clamped with a pinch-cock.

A little of the water is first drawn off and the separating vessel rinsed with it. The end of the rubber tube is then passed to the bottom of the separating vessel, the pinch-cock opened, and the water allowed to flow in until the vessel is not only full, but a fair quantity has overflowed. In this way the possibility of error owing to absorption of atmospheric oxygen by the upper layer of the water as it flows into the wide part of the vessel is avoided.

The stopper is now inserted, and the excess of water drained off. The stopper is next removed, and about 7 c.c. of the water taken out by a pipette and thrown away. Five c.c. of the ferrous sulphate solution are then carefully measured off in an accurately graduated pipette and allowed to flow into the separating vessel, the nozzle of the pipette being just dipped below the surface of the water, when the ferrous sulphate, owing to its higher density, flows in a stream to the bottom of the water. Strong ammonia solution is then cautiously poured on to the top layer of the water until the vessel is just full, when the stopper is inserted ; but even if a drop or two of the ammonia is lost when inserting the stopper no harm is done, as the ammonia floats on the surface and does not appreciably mix with the contents of the vessel. A little dexterity is necessary in inserting the stopper so that no air bubble is enclosed. Within the separating vessel there is now a layer of ferrous sulphate below, next the water, and above all the ammonia. These are mixed together by inverting the vessel once or twice by a swinging motion, when a greenish turbid mixture results, containing ferrous hydrate partly in solution and partly in suspension, which rapidly darkens as it absorbs the dissolved oxygen. In all our first experiments an interval of fifteen minutes was allowed for the purpose. Experience has shown it to be sufficient, but it is possible that a shorter period would suffice.* The next operation consists in inverting the vessel, still stoppered, and then filling or nearly filling its tube or lower extremity (now, however, its upper extremity) with the mixture of sulphuric acid and water (Fig. 2). The stop-cock is then opened, when the acid flows downwards into the alkaline mixture, and in the course of a few minutes dissolves the iron hydrates to a clear solution.†

Should an air-bubble remain in the boring of the stop-cock it prevents this flow, but a few taps cause it to be displaced and to rise through the acid.

The presence of this air bubble can be avoided by opening the stop-cock for a moment when the absorbing vessel is being filled with the water sample. The acidulated solution is finally run off into a porcelain dish, and titrated either with the permanganate or bichromate solution.‡

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* More recent experiments have shown that a period of five minutes is sufficient, as the following results show :—

Dissolved oxygen in Belfast water supply (T. = 7·3) found after the ferrous hydrate had acted for :—

5 minutes.	10 minutes.	15 minutes.
8·34	8·37	8·37 c.c. per litre.

† In some of the test experiments with distilled water saturated with air this did not occur until the mixture was heated. But with all samples of natural waters, sewage effluents, etc., no heating was necessary.

‡ A somewhat lengthy experience of the process when bichromate is used has satisfied us that when very accurate results are desired attention should be paid to the following details :—(1) A clear crystal of potassium ferricyanide, or fragments of such crystal, about the size of a shot (say ⅛-inch in diameter), is placed on a small beaker, and washed two or three times with distilled water. It is then dissolved in about 10 c.c. of the same liquid. Some of this (straw-coloured) solution is drawn into a pipette with a fine capillary end, and a series of minute drops are placed by its means on slab of milk glass. (A white tile is not so satisfactory, as it is liable to become stained after some time.) (2) In titrating, as large a drop as can be carried on a glass rod from the dish is jerked into one of the minute drops of the ferricyanide without touching the latter with the rod itself. The " end reaction " is shown by there being no visible difference in colour after an interval of two minutes between the drops thus made and a similar one formed of distilled water and the ferricyanide. The end reaction is very sharp, and with a little experience is determined by less than 0·03 c.c. of the bichromate solution (about 1 drop from a 10 c.c. burette). (3) Strong sunlight disturbs the end reaction in the case of polluted waters (probably by the well-known reducing effect of light on a ferric salt in presence of organic matter). This can be easily demonstrated by placing on the white glass slab two similar drops of the ferricyanide and the titrated mixture when the end reaction has just occurred—shading one (say with a pill-box lid) and exposing the slab to sunlight for a few minutes, when the unshaded drop becomes blue, while the shaded drop remains faintly yellow. This action is especially noticeable with polluted sea-water. The titration can be performed by artificial light—preferably incandescent electric light, the end reaction being very sharp. (4) As only 5 c.c. of the standard bichromate are required at maximum for each titration or standardisation, a burette of this capacity and divided into twentieths of a cubic centimetre might be advantageous for very accurate work.

It remains to determine the value of the ferrous sulphate solution; and in our experiments this was always done under similar conditions to those obtaining in the dissolved oxygen determination itself, that is to say, the measuring vessel was filled with the water under examination, 7 c.c. removed, and the remainder poured into a porcelain dish, where it was mixed with the same volume of sulphuric acid * and the same volume of ferrous sulphate solution as were employed in the dissolved oxygen determination, and the mixture then titrated. In this way the error arising from oxidisable substances in the water is eliminated even when their amount is considerable.

In practice it was found convenient to standardise the iron solution during the interval required for the absorption of the dissolved oxygen, and consequently, as a preliminary to the latter process, to first of all fill the separating vessel with the water under examination and to transfer the latter (after removing 7 c.c.) to a porcelain dish ready for the addition of the sulphuric acid and ferrous sulphate.

Calculating the Results.—With the stronger solution of either the permanganate or bichromate, it is obvious that the amount of dissolved oxygen contained in the volume of water operated on is expressed in cubic centimetres at N.T.P. by the difference between the burette readings for the blank experiment and those of the actual determination—with a correction for the dissolved oxygen contained in the 5 c.c. of the ferrous sulphate solution and the 2 c.c. of ammonia. Such a correction is, however, small, and in all the authors' experiments, the assumption was made that the 7 c.c. of mixed reagents contained the same proportion of dissolved oxygen as the water under examination.†

Cases in which the method unless modified ceases to give accurate results.—Nitrites in a water exercise a very distinct disturbing effect, and from the test experiments such an effect is produced when the quantity of nitrite corresponds with about 0·1 part per 100,000 of nitrous nitrogen. On the other hand, when the amount is one-tenth as much, no perceptible error is introduced.

Nitrates alone in a water, even in considerable quantities, scarcely if at all affect the determination. But in the case of sewage effluents containing a high proportion of nitrates *which have been kept for some time in closed vessels*, serious discrepancies have been observed between the result of the volumetric and gasometric methods of analysis, although quite concordant results were obtained by the two methods with such samples at the time of their collection.

The following modification of the process in such cases has led to a correction which is sufficient for all practical purposes:—

A solution of acid permanganate (freshly prepared before each series of determinations, as it does not keep well) is made by mixing three volumes of the permanganate solution used for the dissolved oxygen determinations (1 c.c. = 1 c.c. of oxygen at N.T.P.), with one volume of the diluted sulphuric acid (equal volumes of water and the concentrated acid). Two c.c. of this mixture are then added from a pipette to the effluent contained in the measuring vessel used in the volumetric method (after removing 2 c.c. of the water). The stopper of this vessel is then inserted, and its contents mixed with a swinging motion, after which they are allowed to remain for ten minutes; 7 c.c. are then removed, the ferrous sulphate and ammonia added, and the process carried out in the usual manner.

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* This should always be added before the ferrous sulphate, otherwise ferrous carbonate may be precipitated and absorb dissolved oxygen.

† Thus, in one of the determinations, the difference between the burette readings for the blank and dissolved oxygen determinations was 2·35 c.c. Assuming that the 7 c.c. of reagent added contained the *same* amount of dissolved oxygen as the water under examination, then the latter contained per litre—

$$\frac{2350}{332 \cdot 5} = 7 \cdot 067 \text{ c.c. dissolved oxygen, per litre, at N.T.P.}$$

Whereas assuming that the 7 c.c. of reagents contained *no* oxygen, the figures become—

$$\frac{2350}{325 \cdot 5} = 7 \cdot 219 \text{ c.c. dissolved oxygen, per litre, at N.T.P.}$$

The difference is 0·152 c.c. per litre, which, for most practical purposes, is unimportant, and the actual error would certainly be much less. The error, so far as the ferrous sulphate solution is concerned, could be eliminated by saturating it with air at the given temperature previous to a determination, and making the deduction, while that from the small volume of ammonia added is too insignificant to need correction.

The blank experiment is conducted in precisely the same way, with the difference that after removing 7 c.c. of the permanganated liquid and adding the ferrous sulphate, sulphuric acid is added instead of ammonia, and the mixture at once run off into a dish and titrated.

(2) COLLECTION AND EXAMINATION OF DREDGINGS.

An examination of the materials composing the superficial layers of the bed of a given sheet of water furnishes in many cases evidence of the extent to which pollution of the water has been occurring more or less *continuously* for a considerable period, or the absence of such pollution, whereas an examination of the water itself, unless conducted systematically and for some time, quite possibly only affords information regarding *transient* pollution.

The solid matters depositing from polluted water contain, it need scarcely be said, a large quantity of organic matter, and this latter may be detected in several ways in a given sample of sand, mud or silt.

(1) If the organic matter is relatively large the sample is black when collected has a foul smell, and is often infested with small red worms.

(2) If moderate, the sample is not black when collected, but becomes so when kept in a moist condition for a few days.

(3) If minute, no visible change occurs in the sample when kept for a prolonged period in a moist state.

Further, on heating a sample of polluted mud, sand, etc., charring occurs, and if the organic matter is present in relatively large amount, visible vapours are emitted of characteristic odour. Also the loss in weight which a given sample experiences when ignited is to some extent an index of the amount of organic matter which it contains.

Lastly, the proportion of nitrogen present in the sample is a measure, and perhaps the most reliable one, of the extent more especially of sewage pollution. As we believe that very valuable information can be gleaned from an examination of the bed of a stream or sheet of water, as regards pollution, and as we are not aware that the subject has received much attention, we think it may be of service to give a brief account of the methods we have employed for collecting and examining samples of dredgings.

Collecting the sample.—For this purpose we have used a small dredge consisting of a rectangular welded frame of bar iron, about 1 in. broad and ¼ in. thick below (where the bag or "poke" is attached), but beaten out fairly sharp above, so as to form an edge which "bites" when towed along the bottom. The dimensions of this frame are 4½ by 7 in.

The bag or "poke" is made of coarse canvas and is about 1 foot long. It is sewn on to the frame with twine passed through the holes made in the former for the purpose. The tow line is attached to and is best worked from a rowing boat going at a very gentle pace, or drifting merely, if the current is strong. A few minutes towing suffices as a rule to fill the dredge, if the bottom is soft.

Examination.

A. Changes on Keeping.—If the sample is light coloured, small tubes are completely filled with it in the moist condition, corked and set aside. In the samples hitherto examined, blackening has occurred in all cases where the percentage of nitrogen (on the dried sample) has amounted to 0·02 and upwards. As this figure probably corresponds with something like half a per cent. of sewage sludge, the test would seem to be a fairly sensitive one.

B. Loss on Ignition.—The sample is dried in a water or air bath, until friable, and then disintegrated by gentle pressure—sufficient to break up cakes of dried mud, etc., but insufficient to pulverize any harder particles, such as pebbles, shells, or coal fragments, and finally sifted through wire gauze.

Two grams of the siftings are then roughly weighed out, transferred to an accurately weighed porcelain crucible, and the latter then heated for an hour at 110° to drive off any traces of moisture. A weighing of the crucible when cold is then made to obtain the exact weight of the dry sample.

The crucible is next heated, gently at first,* and observations made as to whether charring occurs with or without the evolution of visible vapour, the odour of the latter if produced, etc. The temperature is then raised to a dull red heat, and the heating continued for two hours.

As most samples of dredgings contain calcium carbonate, it is advisable, before weighing the ignited sample, to treat it with ammonium carbonate, to reconvert any lime produced by the ignition into the carbonate. For that purpose 2 c.c. of a saturated solution of the salt are added to the contents of the crucible, and the latter heated (very gently at first) on a water bath, until its contents are dry. Finally it is heated for a minute or so to dull redness, then cooled and weighed.

[The loss which a given sample thus experiences when ignited affords no doubt some indication of the amount of organic matter which it contains, but we regard it as a rough test merely. Very probably a considerable loss on ignition, coupled with a low proportion of nitrogen, indicates vegetable organic matter; while a similar loss on ignition, coupled with a high proportion of nitrogen, probably points to sewage solids. But the number of determinations of the kind which we have as yet made with dredgings scarcely warrant us in framing anything like definite rules on these points.]

C. Nitrogen.—One gram of the sample, roughly dried and pulverized as already described, is placed in a weighing tube, and the latter heated for an hour or so at 110° C. to drive off traces of moisture, cooled and weighed.

The contents of the tube are next shaken into a small Kjeldahl flask; 4 c.c. of pure sulphuric acid added, together with 0·5 gram potassium sulphate. The flask is then heated over a ring burner and its contents kept in fairly vigorous ebullition at first; but later, as bumping usually occurs, the flame is lowered, so that while acid volatilizes no actual ebullition occurs. It is advisable to slope the flask during the heating process to as obtuse an angle as possible. As a rule about three hours is necessary for this part of the process, *i.e.*, until the liquid is colourless, indicating complete oxidation of the organic matter. The contents of the flask, when cold, are next shaken with successive quantities of ammonia-free distilled water (200 c.c. in all), the liquid in each case being decanted from the sand into a distilling flask of about 300 c.c. capacity. Finally, excess of a strong solution of (ammonia-free) caustic potash is added, the alkaline mixture distilled, and 100 c.c. collected.

Portions of the distillate (1–25 c.c., according to the amount of nitrogen in the sample) are then Nesslerized in the usual way.†

In order to calculate the probable percentage of sewage sludge present in the dredging from the percentage of nitrogen found by the above method, it was necessary to determine the nitrogen in sewage sludge itself. Accordingly a number of samples of that material were dried, pulverized, sifted and their nitrogen contents determined as described above, using, however, less of the sample (about one-tenth). The average of nitrogen thus found‡ on the dried sample amounted to 2·7 per cent. But unpolluted sand or mud contains a certain amount of nitrogen (due to animal and vegetable *débris*), for which allowance should be made, and this amount we have taken as being 0·013 per cent. (in the dried sample), the lowest quantity found by us in the purest samples of dredgings or exposed sand which we have examined.

The figures for the "probable percentage of sewage sludge" given in our tables of results have therefore been calculated by the formula :—

$$\frac{100 \times (\text{percentage of nitrogen in the dredging} - 0{\cdot}013)}{2{\cdot}7}$$

E. A. L.

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* Certain samples, and more especially such as consist mainly of sand, must be heated cautiously at first, with the lid of the crucible on, as the particles are apt to fly.

† As the purest sulphuric acid of commerce usually contains appreciable quantities of ammonia, a blank experiment must be made, and best with the same quantities of sulphuric acid, potassium sulphate, water and caustic potash solution as employed in the above process, the quantity of ammonia found in 100 c.c. of the distillate being deducted from that found in the actual determination. Our blank experiments thus conducted have shown a total of about $\frac{10-13}{100}$ milligrams of ammonia.

‡ The amount no doubt varies considerably in different localities, but in order to render our results comparable with each other in different localities we have in all cases adopted the figure 2·7.

SECTION 7A.

EXAMINATION OF
SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

BELFAST.

BELFAST.

Belfast is situated on the Lagan river, a stream which is locked about a couple of miles above the centre of the city, and is there used as a canal. The amount of fresh water descending the river is at ordinary times inconsiderable. The mouth of the Lagan is now formed by two artificial embankments, called the "Twin Islands," which extend for some half mile into what was formerly Belfast Lough, but which has now to some extent been reclaimed in its highest reaches.

The tidal region of the river from its mouth to the first lock is about four miles in length, of which the first two consist of a dredged channel used by shipping.

The population of Belfast was, at the last census (1901), nearly 350,000, and is now nearly 400,000; the city has grown very rapidly, as the following figures show:—

Census.	*Population.*
1821	37,000
1831	53,287
1841	70,447
1851	87,062
1861	121,602
1871	174,412
1881	208,122
1891	255,950
1901	349,180
1907 (estimated)	370 163 – 384,293

The chief industries are linen, and shipbuilding, but distilling is also an important trade. as well as the manufacture of aerated waters.

With the possible exception of distilling, it is improbable that the local industries affect the nature of the sewage of the city to any appreciable extent, as the crude treatment of the flax fibre is done in the country districts, which treatment, so far as the linen trade is concerned, is alone likely to affect the sewage. The shipbuilding industry gives rise to no trade effluents, and the quantity of the latter from the aerated water factories is in all probability not only small, but also of a nature not likely to have any distinct influence on the sewage.

Regarding the question of sewage disposal formerly (as was, at that time, the general practice nearly everywhere under similar conditions), the sewage of the town was discharged into the river—through a number of out-falls—with the usual result in the case of a relatively small river and a rapidly increasing population, viz., that the former became exceedingly foul, its bed becoming coated with black offensive mud and its waters turbid, while the stench at low-tide and in warm weather was most offensive. But as far as we have been able to ascertain, some fifty or sixty years ago Belfast Lough was quite unaffected; its waters were clean and clear, and bathing was freely indulged in quite close to the city. Moreover, the vegetation in the upper reaches of the Lough then consisted chiefly of the *Zostera marina* or sea grass, and green seaweeds of the *Ulva* or *Enteromorpha* species were practically absent.

But with the progress of time, and as the population of the city increased, changes occurred in the nature of this vegetation. The *Zostera* gradually gave place to *Ulva latissima*, and different species of *Enteromorpha*, both of which latter began to occasion a nuisance when they were washed ashore and putrefied in warm weather. This nuisance, at first no doubt slight, became increasingly extensive and acute, and eventually became so serious as to demand public action.

In the year 1890 a Local Government Board Inquiry was held under the Public Health Act (Ireland), 1878 with reference to an application by the Belfast Board of Guardians, acting as the Rural Sanitary Authority of the Belfast Rural Sanitary District for a provisional order to form a united district for the purpose of abating the nuisance, caused (it was then stated) partly by sewage and partly by seaweed, on the foreshore situated between Connswater, immediately adjoining the City of Belfast, and Cultra Pier in the County of Down—this nuisance being injurious to health. At this inquiry it was stated that the nuisance had been patent for twenty years, and that ten years previously proceedings were taken on the part of the Board of Guardians against persons who they thought responsible, to compel them to abate it at that time. This went before the Court of Summary Jurisdiction, who gave a verdict for the Guardians; but that was appealed against, and as the result of a long legal discussion the order was reversed. From that down to 1889 nothing really practical was done for the abatement of the nuisance. Proceedings were then instituted against the owner of the land adjoining the foreshore for the purpose of compelling him to abate what was admittedly a nuisance, and this eventuated practically in nothing, because the magistrates thought they had power under the Public Health Act (116th sec.) to direct the Guardians themselves to abate the nuisance, but as they found they had not the power to do that, the defendant's name as owner of the property being known in Court, the case was dismissed. As it was known to be a nuisance which was more or less contributed to by the City of Belfast through its sewage, and by the town of Holywood by its sewage, it was thought reasonable and fair that what was necessary to remove this nuisance should be done in some degree by each body, the Board of Guardians joining with these other two.

The result of this inquiry was that a Provisional Order of the Local Government Board for Ireland was issued and confirmed by Act of Parliament (53 & 54 Vict. Ch. xci.) whereby a united district was formed for the purpose of abating the nuisance between Connswater and Cultra Pier, consisting of the Urban Sanitary District and part of the Rural Sanitary District, but at the expressed desire of the city authorities the city itself was not included in this united district. The united district was controlled by a governing body consisting of *ex officio* and elected members representing the different authorities concerned.

The expenses of the Joint Board were provided for as follows: the Corporation of the City of Belfast to contribute for three years one half of the cost incurred in removing the offensive deposits and abating the nuisance, provided that the total amount to be thus contributed should not exceed £300, the balance to be defrayed out of a common fund to be contributed by the component districts.

In the year 1889 a new main drainage system was commenced in Belfast consisting of two main trunk sewers through the city and two pumping-stations, together with a large underground reservoir for storing the sewage previous to discharging it (on the ebb tide only) through a submarine timber "shoot" which extends for about a mile into the Lough.

As it was anticipated that this new drainage system would either completely prevent the nuisance or materially abate it, the Provisional Order above referred to was made operative for three years only, to enable the new drainage system to be completed, and to come into operation. At the end of that time the Joint District and the Joint Board passed out of existence.

The effects of the new drainage system soon become manifest in two totally opposite directions. On the one hand, the condition of the river rapidly improved, the foul mud banks soon got cleaner and the water clearer, and at the present time the river is quite clean and no nuisance ever arises from it, even in the hottest weather. But, on the other hand, and quite contrary, apparently, to the opinion of those responsible for the scheme, the state of the Lough rapidly became worse. Increasing quantities of green seaweeds made their appearance each year and were washed ashore, forming deposits often several feet thick * and these deposits were found much further down the Lough than formerly, and extend at present on the south side nearly three miles seawards of Cultra, which place, as already stated, was fixed as the limit of the nuisance in 1890.

The nuisance occurring during the summer months from the putrefaction of these masses of green seaweed soon became intolerable, the stench extending over a wide area and occasioning not only great discomfort to the inhabitants of the district, but also causing, in many cases, nausea, headache and sore throat. White paint on boats, houses, flagstaffs, etc., at times turned black in a single night, and silver plate tarnished so rapidly that it could scarcely be kept bright. Indeed, occasionally, the nuisance was so acute and the evolution of sulphuretted hydrogen so extensive, that paper moistened with acetate of lead solution held near one of the seaweed deposits, turned black in a few minutes.

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* At the time of writing this, a deposit fully three feet in thickness and absolutely putrid is being removed from the shore at Holywood. [Nov. 1905.]

Fresh remedial measures were obviously imperative, and as by this time it had been clearly demonstrated that the nuisance was caused by seaweed and seaweed only, and not directly by sewage matters entangled in them,* and further, that the growth of these particular seaweeds is encouraged, or rather depends upon, sewage pollution of the water, it seemed clear that the main drainage scheme was largely responsible for the trouble, and, therefore, the city.

As a consequence the inhabitants of the districts where the nuisance was most acute approached the city authorities on the subject, and eventually in 1899 the latter undertook by Act of Parliament to purify the sewage of Belfast before discharging it into the Lough, the necessary works and appliances to be provided within three years from the passing of the Act: while both the system of treatment and the method of putting the same into operation adopted by the corporation were to be subject to the approval of the Local Government Board (Ireland).

Meantime the nuisance not only continued, but, if anything, became even more aggravated, while for several reasons the city authorities found it impossible to fulfil their obligation to complete the scheme of sewage purification within the specified time. Two of the chief reasons for this ought to be mentioned. In the first place, it was open to serious question whether the ordinary methods of sewage purification would necessarily lead to the extermination of the green seaweeds which were the essence of the trouble. The problem was, in fact, quite a new one in the history of sewage purification, and if, on the one hand, the ratepayers' money was not to be wasted, and, on the other, the Local Government Board were to give their sanction to the scheme, the whole subject ought to be submitted to scientific investigation.†

The second reason was even more cogent, namely, that the land available for the purification works was quite too small for the purpose, and could only be enlarged to the necessary size by an extensive reclamation of slobland—a work necessarily involving considerable expenditure of time.

Another Local Government Board inquiry was held in January, 1904, with reference to an application made by the Rural District Council, praying for a Provisional Order to again constitute a united district for the purpose of abating the nuisance. This application was to a certain extent opposed by the city authorities, but eventually the petition was withdrawn and a compromise arrived at whereby the city agreed to contribute for one year, two-thirds of the ascertained cost of cleansing of the foreshore—excluding the Holywood foreshore—which remained in charge of the Urban District Council. The two-thirds to be contributed by the city not to exceed £250.

The actual outlay for the purpose during the year amounted to £430, but it was found that this expenditure was quite inadequate for removing the nuisance, though the latter was undoubtedly ameliorated to some extent. Very large quantities of the decaying seaweed, however, remained uncollected after all the available funds had been expended and it became obvious that the cost of the removal had been altogether underestimated As a consequence, the chief responsible sanitary authority (now the Castlereagh Rural District Council) once more approached the Local Government Board, with a petition to again form a united district, and for a Provisional Order for the purpose, this time under Section 12 ‡ of the Public Health Act (Ireland) 1878; the united district to include Belfast itself in addition to the two other sanitary districts involved, namely, Castlereagh and Holywood.

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* See Section 3, pp. 141-168.

† This was done, the work being entrusted to one of us as chemist, in association with Professor Lorrain Smith as bacteriologist. Two Reports have been presented to the Corporation dealing with the chemical investigations made and one on the bacteriological investigations. The work is now approaching its conclusion and we hope to issue the final Report shortly (see Section 4, pp. 171-194.)

‡ The section is as follows:—

"Where it appears to the Local Government Board on the application of the sanitary authorities any sanitary districts, or of any of such authorities and after due inquiry, that it would be for the advantage of such sanitary districts, or of any of them or of any parts thereof, or of any contributory places in any rural sanitary district or districts, that they should be formed into a United District for all or any of the purposes following, that is to say (1) The procuring of a common supply of water; or (2) The making of a main sewer or carrying into effect a system of sewage for these or all such districts or contributory places; or (3) For any other purpose of this Act, the Local Government Board may by Provisional Order form such district or contributory places into a United District." And the succeeding portions of the section deal with the methods by which the costs, charges and expenses incurred are to be defrayed.

The Local Government Board Inquiry regarding this petition was held in Belfast on the 14th, 15th, and 16th of December, 1904, under the Board's chief engineering inspector, Mr. P. C. Cowan, and Dr. Edgar Flynn, medical inspector, and went very thoroughly into the whole question of the nuisance: its origin, sources, and the probable annual cost of removing the seaweed. As a result of the inquiry a Provisional Order was made by which the proposed united district was formed, together with a joint board to deal with it, composed of representatives from all three districts. The maximum expenditure for any one year was limited to £2,000 of which the Belfast contribution was to amount to 85 per cent. or £1,700, while the remaining 15 per cent. or £300 was to be equally distributed between the two other districts, namely, Castlereagh and Holywood.

But at the expiration of five years from the passing of the Act confirming the order, power was reserved to the Local Government Board to vary to such extent as may appear equitable, the amounts to be respectively contributed by the component authorities. The order was opposed by the city authorities, but eventually received the Royal assent on August 4th, 1905.*

* * * * * *

Passing now from the history of the nuisance in Belfast Lough and of the action which has been taken from time to time by the responsible sanitary authorities to abate it, we come next to the investigations which one of us has made on the present condition both of the waters of the Lough and also of its bed. But before describing these it appears to be advisable to give a few topographical particulars of that sheet of water.

The Lough is horn-shaped, the point of the horn corresponding with the mouth of the river, and the broad extremity with the opening of the Lough into the Irish Channel.

The southern or county Down shore is situated on the inner side of the curve, and the northern or county Antrim shore on its outer side; the general trend of the curve from the mouth of the Lagan to the Irish Channel being roughly north-east.

The distance from the mouth of the river to Black Head (the northern extremity of the Lough) is about thirteen miles as the crow flies, and from the same spot to Orlock Point (the southern extremity), much the same distance.

At the mouth of the river (or end of the Twin Islands) the Lough is about two-and-a-half miles wide. At Grey Point (situated about seven miles from the mouth of the river) somewhat under three-and-a-half miles, after which it broadens out rapidly, the distance between Orlock Point and Black Head being about seven miles.

The upper reaches of the Lough are very shallow, and extensive mud and sandbanks are uncovered at low water, which reach almost from shore to shore near the city, and continue for fully four miles down each side seawards, though gradually diminishing in width.

Regarding the tides, the main body of the outer (or Irish Channel) stream (both ebb and flood) crosses the mouth of the Lough in a curve from the Copeland Islands to Black Head (or *vice versa*), and near the islands gains a strength of five knots; this curve bends more and more until it stretches from White Head to Grey Point, where it divides; one part of the flood running up towards the city, the other bending back and running towards Orlock. The stream in the Lough itself rarely exceeds a knot in strength† and in the upper reaches is certainly much less, but neither the strength nor direction of the current from Grey Point to the city appear on the Admiralty charts. We shall allude to the question of these currents later, as it has a very important bearing on that of the discharge of sewage from the city.

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* [5 Edw. 7] Local Government Board (Ireland) [Ch. CXXIII.] Provisional Orders Confirmation (No. 2) Act 1905.

† Sailing directions for St. George's or Irish Channel.

SURVEY OF THE UPPER REACHES OF BELFAST LOUGH IN RELATION TO THE STRENGTH AND DIRECTION OF THE TIDES, CHEMICAL EXAMINATION OF THE WATER AND BED, AND CORRESPONDING BACTERIOLOGICAL EXAMINATION.

Originally a chemical examination of the waters of the Lough at different places and at different states of the tide was alone contemplated, but very fortunately, owing to causes which need not be specified here, the inquiry became more extended, and eventually embraced a series of float experiments, conducted by Mr. Cutler, the City Surveyor of Belfast, and Mr. Napier, who is in charge of the sewage works of the city generally, in relation to the strength and direction of the tides in the upper reaches of the Lough, with simultaneous collection of samples of water and of dredgings for chemical examination by one of us, and for bacteriological examination by Dr. Carnwath, who very kindly volunteered to do the work. The float observations were made as a rule from a steam yacht, samples of water and dredgings being collected as nearly as possible at the same time. The temperature of the water was also taken, and, as a rule, a determination of the dissolved oxygen (by the volumetric process, see p. 221) was made in addition.

The localities from which the samples of water and dredgings were collected in each series, and the movements of the floats when the latter were employed are given in a set of charts of Belfast Lough, while the results of the chemical and bacteriological examinations of the water and dredgings are given in a corresponding set of tables.

The first chart is on a smaller scale than the others and shows the general features of the Lough from the open sea to the city, and also the general distribution of the *ulva latissima* which is indicated by green dots.

A word may here be said regarding the figures which appear in the tables giving the ratio of free to albuminoid ammonia.

The actual amount of free ammonia in Belfast sewage is probably on an average about 2½ parts per 100,000, while that of the albuminoid ammonia is somewhat less than half that quantity, and the ratio of the two may perhaps be taken as 1 : 0·4.*

The actual amount of free ammonia in pure sea water is very small, and from our own work on the water of the Irish Channel, we are inclined to fix the amount at not more than 0·001 parts per 100,000. The amount of albuminoid ammonia is quite distinctly higher, no doubt owing to the presence of minute organisms, and it may amount to 0·005–0·006. Here then the ratio between the two figures (1 : 5 or 1 : 6) is very different from the sewage ratio.

It is generally held that a high proportion of free, in relation to albuminoid ammonia in a given water sample indicates pollution from animal sources, and as a rule, from sewage, the converse pointing to vegetable pollution.† Hence, in ordinary waters the ratio of the two is considered to be of importance in deciding as to the nature of the impurity. But in Belfast Lough (and no doubt in other places of a similar kind), the problem is complicated by the remarkable rapidity with which the green seaweed *ulva latissima* absorbs free ammonia. Consequently a low proportion of free ammonia, coupled with a high proportion of albuminoid ammonia in a given sample of the Lough water, may indicate one or other of two things, namely, either that the sample contains vegetable pollution only (say from the rotting *ulva* itself), or that the free ammonia originally derived from sewage pollution has been removed by the living *ulva*.

As the living *ulva* disengages oxygen rapidly, an excess of oxygen in a given water sample would indicate the latter effect.

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* The ratio in some other large towns is not very different, and would appear from the published analyses to vary between 1 : 0·25 and 1 : 0·44 (*See* p. 313.).

† While this is no doubt true in a great number of cases, it may be questioned whether it is so invariably, and it seems desirable that, when possible, determinations both of the organic nitrogen (by Kjddahl's method) and of the albuminoid ammonia should be made until sufficient evidence is obtained of the relationships under different circumstances between the two.

BELFAST LOUGH—FIRST SERIES—OCTOBER 25th, 1904.

SAMPLES collected during the commencement of the Ebb—H.W., 10.59 a.m.

SPRING TIDE—[FULL MOON—OCT. 24th.]

WATER SAMPLES.

CHEMICAL EXAMINATION.

No.	Where Sample was Collected.	Time.	Temp°C.	Chlorine. (Parts per 1,000.)	Dissolved Gases (c.c. per Litre at N.T.P.)					Nitrogen (parts per 100,000).		Ratio.	
					At time of Collection.	After keeping.							
					Oxygen.	Oxygen.	Loss of Oxygen.	Carbonic Anhydride.	Nitrogen.	Free Ammonia.	Albd. Ammonia.	Free Ammonia : Albd. Ammonia.	
6	At mouth of River Lagan - -	1.50 p.m.	10·4	17·70	4·11	3·64	0·47	54·11	12·08	0·056	0·020	1	0·4
5	In Channel at No. 5 Buoy, 2 knots from river's mouth.	1.13 „	10·6	19·02	5·70	—	—	—	—	0·017	0·010	„	0·6
4	In Channel between Nos. 1 and 2 Buoys, 3 knots from river's mouth.	12.50 „	10·9	19·20	6·00	5·85	0·15	—	—	0·010	0·009	„	0·9
3	Outside Lighthouse, 4 knots from river's mouth.	12.25 „	11·1	19·24	5·82	5·83	0·00	47·69	11·49	0·008	0·007	„	0·9
2	Middle of Lough, 5 knots from river's mouth.	12. 5 „	11·2	19·24	—	6·00	—	—	—	0·007	0·009	„	1·3
1	Middle of Lough, 7 knots from river's mouth.	11.40 a.m.	11·35	19·22	6·00	5·96	0 04	47·03	11·39	0·005	0·007	„	1·4

BACTERIOLOGICAL EXAMINATION.

Sample number.	1. Total number of Bacteria in 1 c.c. capable of growing on		2. Number of Gas-forming Microbes in 1 c.c.					3. Number of B. Coli in 1 c.c.					4. Chief biological characters of the strain of B. Coli isolated from the quantity specified in Col. 3.					5. Bacillus enteritidis sporogenes test.					6. Number of streptococci in 1 c.c.				
	Gelatine, at 22 C.	Agar, at 37 C.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	Gas (glucose broth, 24 hours at 37°C.)	Gelatine (characteristic non-liquefying growth).	Indol (peptone water, 5 days at 37°C.)	Milk Cultures (5 days at 37°C.		·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1000 ·001 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1000 ·001 c.c.
																Acidity.	Clot.										
6	4,000	1216	+	+	+	+	–				+	–	+	+	+	+	+	+	–	–	–	–	+	+	+	+	–
5	110	11	+	+ ?	–	–	–	–	–	–	–	–						–	–	–	–	–	–	–	–	–	–
4	100	6	+	–	–	–	–	+	–	–	–	–	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–
3	300	4	–	–	–	–	–	–	–	–	–	–						–	–	–	–	–	–	–	–	–	–
2	350,000	760	+ ?	–	–	–	–	–	–	–	–	–						–	–	–	–	–	–	–	–	–	–

DREDGINGS.

BACTERIOLOGICAL EXAMINATION .

Numbers are given per gramme of undried mud.*

Sample Number.	1. Total number of Bacteria in 1 gm. capable of growing on		2. Number of Gas-forming Microbes in 1 gm.					3. Number of B. Coli in 1 gm.					4. Chief biological characters of the strain of B. Coli isolated from the quantity specified in Col. 3.					5. Bacillus enteritidis sporogenes test.					6. Number of streptococci in 1 gm.				
	Gelatine at 22° c.	Agar at 37° c.	·1 10 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.	1,000 ·001 gm.	·1 10 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.	1,000 ·001 gm.	Gas (glucose broth, 24 hours at 37° c.)	Gelatine (characteristic non-liquefying growth).	Indol (peptone water, 5 days at 37° c.)	Milk Cultures, 5 days at 37° c. Acidity.	Milk Cultures, 5 days at 37° c. Clot.	·1 10 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.	1,000 ·001 gm.	·1 10 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.	1,000 ·001 gm.
6	437,000	157,000	+	+	+	+	+					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
			(about 1,610 per gm.)					(about 161 per gm.)										(about 1,610 per gm.)					(about 1,610 per gm.)				
5	300,000	120,000	+	+	+	+	–	?	?	?	–	–						+	+	+	–	–	?	?	?	–	–
			(about 300 per gm.)					(absent from ·0336 gm.)										(about 30 per gm.)					(absent from ·0336 gm.)				
4	4,600	4,270	+	+	–	–	–	?	?	?	–	–						+	+	–	–	–	?	?	?	–	–
			(about 3·8 per gm.)					(absent from ·026235 gm.)										(about 3·8 per gm.)					(absent from ·026235 gm.)				

* Moisture of No. 6 = 52%
„ „ 5 = 53%
„ „ 4 = 42%

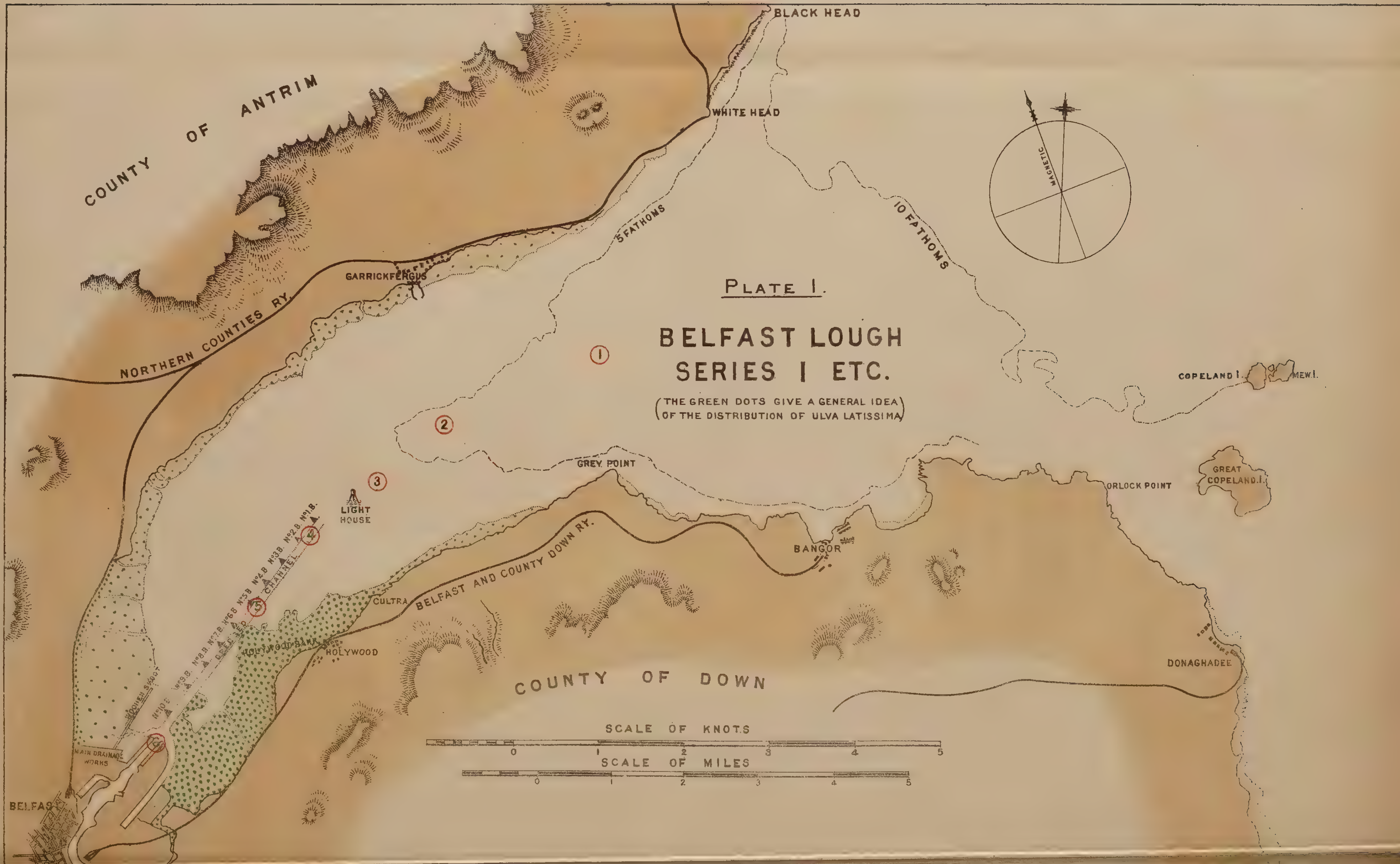


PLATE I.

BELFAST LOUGH SERIES I ETC.

(THE GREEN DOTS GIVE A GENERAL IDEA OF THE DISTRIBUTION OF ULVA LATISSIMA)

SERIES 1.

In this series the samples were collected on the ebb tide, and, as will be seen from the numbers, in the reverse order from that given in the table—that is to say, from about half way down the Lough to the entrance of the river. Unless otherwise stated all the samples examined both in this and in the other series were collected a few inches below the surface.

Chemical Examination.

Pollution.—The diminution of pollution as the city is left and the open sea approached is well brought out by the gradual falling off in the free ammonia, and it will also be noticed from the figures that whereas the ratio of free to albuminoid ammonia is, in the river, the sewage ratio, *i.e.*, 1 : 0·4, it rapidly alters and eventually becomes 1 : 1·4.

The influence of the pollution in lowering the dissolved oxygen originally present is very apparent in No. 6, as also the loss in that factor when the sample was kept. In No. 5 there is still a slight deficiency in dissolved oxygen, but in the other samples the amount originally present is in the correct ratio to the nitrogen found, for the air saturation values; but it should be noted that the figures agree with a *higher* temperature than that observed. Thus in No. 3 the oxygen found was 5·83, the nitrogen 11·49, and the temperature of the sample 11·1°C. Whereas the air saturation values at 15°C. for sea water are 5·83 and 11·34 respectively, and at 11° C. 6·31 and 12·23.

Temperature.—The temperature, it will be seen, varied from 10·4° C. in the river sample to 11·35 in the most seaward sample, and the rise in temperature as the sea was approached was fairly regular. Probably the water covering the shallow banks was cooled down during the night, or the banks themselves when exposed at low water were cooled down, and in their turn cooled the tidal water as it flooded them, whereas, owing to the effects of the Gulf Stream the true ocean water has at this time of the year a higher temperature.

Salinity.—The salinity increased as might be expected as the river was left, and the open sea approached, and therefore on the whole increased with the temperature. No. 1 appears to be anomalous in this respect, but this is quite possibly due to an observational error.

Bacteriological Examination.

No. 6. Both the chemical and bacteriological examinations agree in indicating distinct sewage pollution. The total number of organisms found both in gelatine and agar was high. *B. Coli* was present in large numbers and *B. Enteritidis sporogenes* and *Streptococci* were found.

No. 5. The chemical examination showed slight pollution, probably due to sewage; but the bacteriological examination gives scarcely any indication of this. The total number of organisms was small, and *B. Coli*, *B. Enteritidis sporogenes*, and *Streptococci* were not found. Gas forming organisms were, however, not quite absent.

No. 4 was found by chemical examination to be distinctly purer than No. 5, and this in respect of the number of organisms found is confirmed by the bacteriological examination. *B. Coli* was however present.

No. 3. The chemical examination of this sample indicated that it was purer than the last. The bacteriological examination, however, showed that it contained three times as many organisms in gelatine medium. But on the other hand the number in the agar medium was less than in the last sample, and no organisms characteristic of sewage were found.

No. 2 contained rather less free ammonia than No. 3, but rather more albuminoid ammonia. The results of the bacteriological examination are remarkable, as an extraordinary number of organisms were found both in the gelatine and agar media. But on the other hand no organisms characteristic of sewage were isolated.

It will be noticed that throughout this series the number of organisms found in the agar cultures diminished continuously from No. 6 to No. 3, and in that respect correspond with the results of the chemical examination. But in other features there are slight discrepancies in the results of the two methods of examination.

BELFAST LOUGH—SECOND SERIES.

SAMPLES collected December 5th, H.W., 8.56 a.m. and H.W. December 6th, 9.43 a.m.

(SPRING TIDE.)

WATER SAMPLES.

CHEMICAL EXAMINATION.

Date 1904.		No.	Where Sample was Collected.	Time.	Temp. °C.	Chlorine. Parts per 1,000.	Dissolved Gases (c.c. per Litre at N.T.P.)					Nitrogen (parts per 100,000) as :—		Ratio.
							At time of Collection.	After keeping.						
							Oxygen.	Oxygen.	Loss of Oxygen.	Carbonic Anhydride.	Nitrogen.	Free Ammonia.	Albd. Ammonia.	Free Ammonia : Albd. Ammonia.
Dec.	5	1A	At the Albert Bridge - -	a.m. 11.30	6·4	6·58	6·73	7·03	0·0	52·58	14·81	·0206	·0230	1 : 1·1
,,	5	2A	At mouth of River Lagan -	12.30	6·5	16·02	5·97	6·03	0·0	51·28	12·94	·0263	·0173	1 : 0·7
,,	6	1	At Lighthouse (in Channel) -	10.0	8·0	19·20	6·42	6·44	0·0	47·67	12·18	·0090	·0082	1 : 0·9
,,	6	2	About 700 yards nearer Holywood than last sample.	10.20	?	19·20	6·39	6·7	0·0	47·88	12·34	·0085	·0092	1 : 1·1
,,	6	3	About 1,000 yards nearer Holywood than last sample.	10.50	7·0	18·82	6·39	6·39	0·0	48·38	12·41	0148	·0099	1 : 0·7
,,	6	4	About 150 yards out from the Marine Parade, Holywood.	11.15	6·25	18·28	6·39	—	—	—	—	·0155	·0115	1 : 0·7
,,	6	5	Off Barracks Outfall - -	11.50	6·5	18·32	—	—	—	—	—	·0263	·0105	1 : 0·4

BACTERIOLOGICAL EXAMINATION.

	1.		2.					3.					4.					5.					6.				
Sample Number.	Total Number of Bacteria in 1 c.c. capable of growing on		Number of Gas-forming Microbes in 1 c.c.					Number of B. Coli in 1 c.c.					Chief biological characters of the strain of B. Coli, isolated from the quantity specified in Col. 3.					Bacillus enteritidis sporogenes test.					Number of streptococci in 1 c.c.				
	Gelatine at 22° c.	Agar at 37° c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	·1 10 c.c.	1 1 c.c.	·10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	Gas (glucose broth, 24 hrs. at 37° c.).	Gelatine (characteristic non-liquefying growth).	Indol. (peptone water, 5 days at 37° c.).	Milk Cultures, 5 days at 37° c.		·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.
																Acidity.	Clot.										
1	605	26	+	+	-	-	-		+	-	-	-	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-
2	570	80	+	+?	-	-	-	+	-	-	-	-	+	+	+	+	+	+?	-	-	-	-	+	+	-	-	-
3	1,300	140	+	+	-	-	-		+	-	-	-	+	+	+	+	+	+	+	-	-	-	+	+	-	-	-
4	3,700	300	+	+	+	-	-			+	-	-	+	+	+	+	+	+	+	+	-	-	+	+	+	+	-
5	1,500	280	+	+	+	-	-			+	-	-	+	+	+	+	+	+	-	-	-	-	+	+	-	-	-

SERIES 2.

In this series two samples of the river water were collected on December 5th, while the day following samples were collected at the Lighthouse and along a line between it and Holywood, the object being to ascertain whether the sewers running into the Lough at Holywood, and from the military barracks situated about a mile nearer the city, had any appreciable effect on the waters of the Lough.

Chemical Examination.

Pollution.—The pollution is of course well marked in the river samples. But in the sample collected at the Albert Bridge (about two-and-a-half miles from the river's mouth), the ratio of free to albuminoid ammonia is roughly 1 : 1 which is not the sewage ratio. At the mouth of the river, however, the latter is approached.

In the samples of December 6th, that collected near the Lighthouse is similar in character to the corresponding sample of the first series, and while fairly pure is not entirely free from pollution. No. 2 is similar in character, but No. 3 shows undoubted pollution, probably of a sewage origin, which increases in Nos. 4 and 5.

Temperature.—This, as in Series 7, is higher towards the open sea than in the river or near land.

Salinity.—In the sea water samples (December 6th) the salinity decreased as the land was approached.

General Inference.—The water is distinctly polluted near the land, probably by sewage, and is comparatively pure near the Lighthouse.

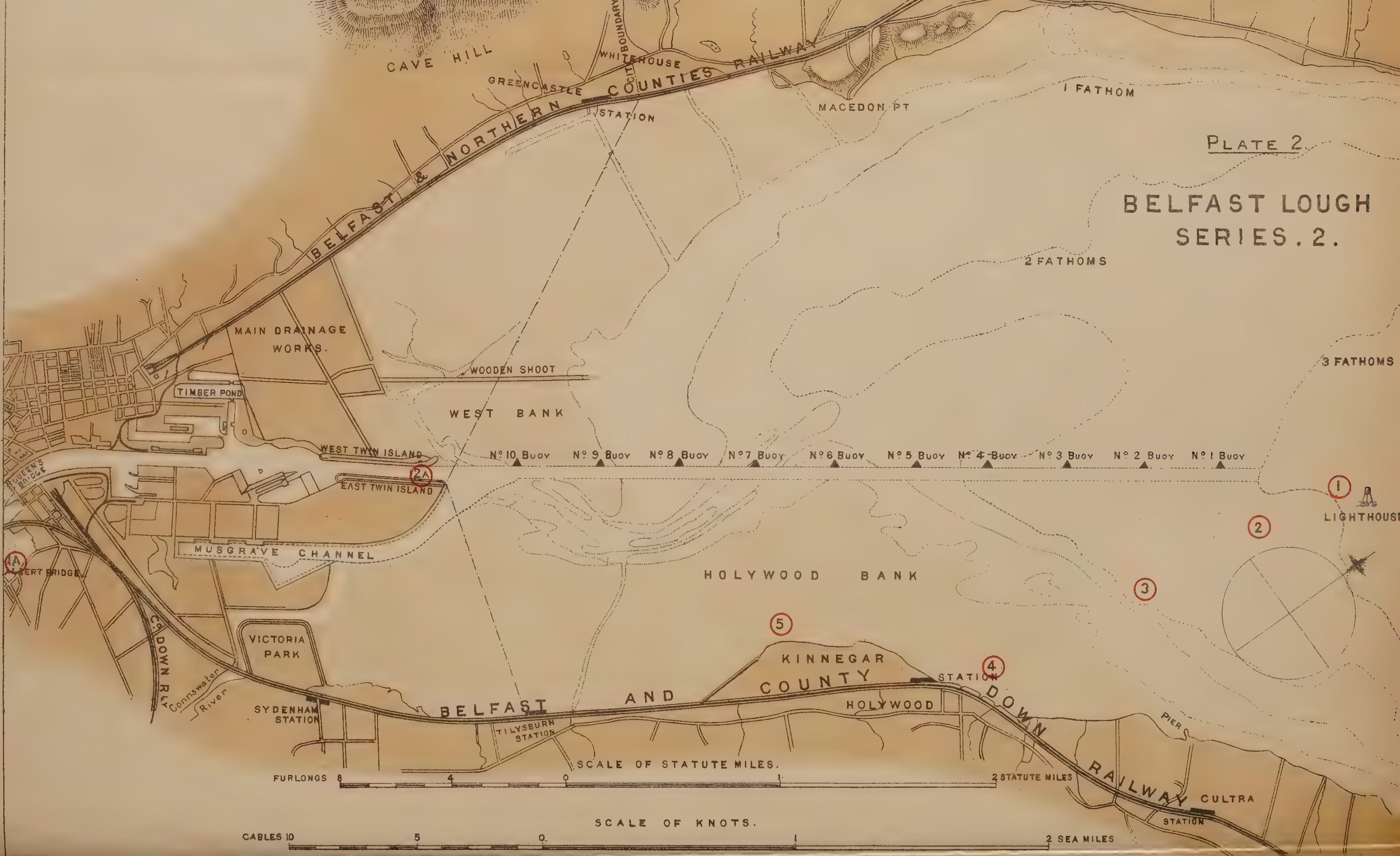


PLATE 2.

BELFAST LOUGH SERIES. 2.

BELFAST LOUGH—THIRD SERIES.

SAMPLES collected June 3rd, 1905 (New Moon this day), H.W., 10.41 a.m.
(SPRING TIDE.)

WATER SAMPLES.

CHEMICAL EXAMINATION.

No.	Where Sample was Collected.	Time.	Temp. °C.	Chlorine. Parts per 1,000.	Dissolved Gases (c.c. per Litre at N.T.P.)					Nitrogen (parts per 100,000) as :—		Ratio.	
					At time of Collection.	After keeping.							
					Oxygen.	Oxygen.	Loss of Oxygen.	Carbonic Anhydride	Nitrogen.	Free Ammonia.	Albd. Ammonia.	Free Ammonia :	Albd. Ammonia.
A	Inside shoot bottom sample - -	11.45 a.m.	—	18·56	—	—	—	—	—	—	—	—	—
B	„ surface „ - -	11.55 „	—	18·40	—	—	—	—	—	—	—	—	—
1	In track of floats „ - -	12.25 p.m.	14·4	18·56	—	2·15*	—	50·87*	11·31*	0·033*	0·026*	1	0·8
2	„ „ „ - -	12.40 „	14·4	18·56	—	2·92**	—	—	—	0·030**	0·021**	„	0·7
3	„ „ „ - -	1.50 „	14·2	18·96	—	5·31*	—	46·17*	11·36*	0·0041*	0·0143*	„	3·5
4	„ „ „ - -	3.0 „	14·2	19·00	—	5·14**	—	—	—	0·0041*	0·0132**	„	3·2
5	„ „ „ - -	3.45 „	14·2	19·08	—	5·33**	—	—	—	0·0033**	0·0165**	„	5·0
6	„ „ „ - -	4.45 „	14·2	19·16	—	5·40**	—	46·06**	11·55**	0·0041*	0·0152*	„	3·7

*Analysed June 6th.
** „ „ 7th.

BACTERIOLOGICAL EXAMINATION.

Sample Number.	1. Total number of Bacteria in 1 c.c. capable of growing on		2. Number of Gas-forming Microbes in 1 c.c.					3. Number of B. Coli in 1 c.c.						5. Chief biological characters of the strain of B. Coli isolated from the quantity specified in Col. 3.						6. Bacillus Enteritidis sporogenes test.				7. Number of streptococci. in 1 c.c.				
																	Milk Cultures (5 days at 37°c.)											
	Gelatine at 22° c.	Agar at 37° c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	·02 50 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	Morphology (motile and gram negative).	Gelatine (characteristic non-liquefying growth).	Gas (glucose, broth, 24 hours at 37°c.).	Acid-ity.	Clot.	Indol. (petone water 5 days at 37° c.)	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c·c.	100 ·01 c.c.	1,000 ·001 c·c.
A	14,000	2,090	+	+	+	–	+						+	+	+	+	+	–	–	–	–?	–	–	+	+	+	?	–
B	24,000	2,690	+	+	+	+	+						+	+	+	+	+	+	–	–	–	–	–	?	?	–	–	–
1	12,500	1,700	+	+	+	+	+						+	+	+	+	+	+	+	–	–	–	–	+	+	+	–	
2	3,300	380	+	+	+	+	–					+	–	+	+	+	+	+	–	–	–	–	–	+	+	?	–	
3	1,050	240	+	+	+	–	–				+	–	–	+	+	+	+	–	–	–	–	–	–	+	?	–		
4	900	80	+	+	+?	–	–			+	–	–	–	+	+	+	+	–	+	–	–	–	–	?	–	–		
5	250	12	–	–	–	–	–	–	–	–	–	–	–	.	.	.	.	.	.	–	–	–	–	–	–			
6	400	21	+?	+?	–	–	–	+	–	–	–	–	–	+	+	+	+	+	+	–	–	–	–	–	–			

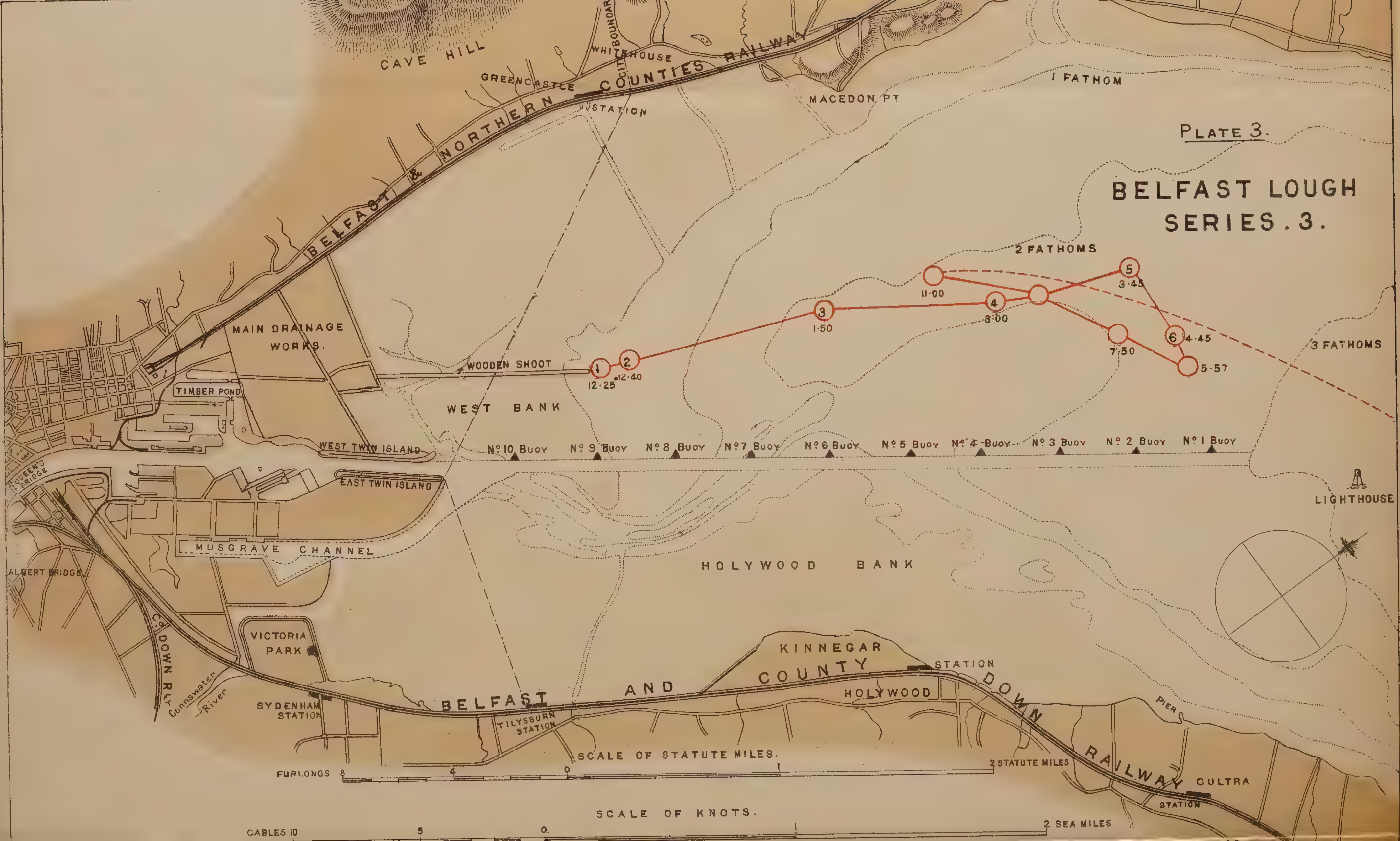


PLATE 3.

BELFAST LOUGH SERIES. 3.

SERIES 3.

This was the first series made with the object of tracing the course of the sewage after its discharge from the "Shoot," as the submarine culvert is called through which the sewage of the city passes from the pumping station into the Lough, and for this purpose floats were employed. These were started an hour after high water at the mouth of the shoot.

On commencing the observations, the presence of sewage was clearly indicated by the floating matters in the water and also by a very distinct odour. A steady westerly breeze was blowing with occasional squalls; the wind undoubtedly had an effect on the floats and probably after a time drove them beyond the sewage current.

By an accident, the apparatus for determining dissolved oxygen in the samples at the time of collection was not brought. Hence the loss in dissolved oxygen on keeping the samples was not ascertained.

(It will be seen that a period of three days elapsed in some cases between the time of collecting and the time of analysing the samples, while in others the period was four days).

Chemical Examination.

Pollution.—Nos. 1 and 2 are decidedly polluted, no doubt mainly with sewage, though the ratio of free to albuminoid ammonia is not quite the sewage ratio. It will be seen that the dissolved oxygen which remained after keeping the samples was small. The nitrogen found points to the presence originally of 5·83 cc. per litre of oxygen (the air saturation value for a temperature of 15°C.), whereas only 2·15 and 2·92 cc. per litre were found respectively in the two samples.

Nos. 3, 4, 5 and 6 are on the whole similar in the analytical features. There is an abrupt diminution in the amount of free ammonia in these samples contrasted with that in Nos. 1 and 2 (about $\frac{1}{8}$), and also a diminution—though not so great in the amount of albuminoid ammonia. Moreover, the ratio between these two factors also changes abruptly.

Temperature.—This, on the whole, was fairly uniform, but there was a slight lowering corresponding with the diminished pollution.

Salinity.—This distinctly increased with the diminution of pollution and the lowering of temperature, but afterwards remained fairly uniform. At this time of the year (summer) a relatively low temperature is probably associated with the stream of fresh sea water entering the Lough from the Irish Channel, and is consequently also associated with a relatively high salinity.

General Inference from the Chemical Examination.—From results subsequently obtained, it seems probable that the floats were slightly in advance of the main sewage current, while from the abrupt change in the character of the samples after No. 2 it seems likely that they were even driven into comparatively pure water.

Bacteriological Examination.

No. 1 is highly polluted as indicated by the total numbers of organisms (whether in gelatine or agar medium) and also by the numbers of *B. Coli* and *streptococci.*

No. 2. is distinctly less polluted as indicated by the numbers of the organisms in the two media. The number of *B. Coli* also falls off, and probably that of the *streptococci* also.

No. 3 appears to be still less polluted as indicated by all the factors.

No. 4. A similar decrease.

No. 5. The water now seems to be fairly free from organisms generally and quite free from those characteristic of sewage.

No. 6. Here a return of pollution appears as indicated both by the total number of organisms and by the reappearance of *B. Coli.*

Contrast of Chemical and Bacteriological Examination.

The chemical examination shows that Nos. 1 and 2 are not very dissimilar, though in most of the analytical characteristics there is a slight difference in favour of No. 2. But bacteriologically there are wide differences as regards the total number of organisms coupled with some difference in the number of *B. Coli* and possibly of *streptococci* also.

In the other samples a progressive improvement is shown bacteriologically up to No. 5. But chemically there is no such distinction. Bacteriologically No. 6 is worse than No. 5, but chemically there is no decided increase in pollution.

On the whole, therefore, in this series there are very distinct discrepancies between the results of the two methods of examination.

BELFAST LOUGH—FOURTH SERIES.

SAMPLES collected June 5th, 1905, H.W. 11.52 a.m.—(Spring Tide).

WATER SAMPLES.

Chemical Examination.

No.	Where Sample was Collected.	Time.	Temp.°C.	Chlorine (Parts per1,000)	Dissolved Gases (c.c. per Litre at N.T.P.)					Nitrogen (parts per 100,000) as :—		Ratio.	
					At time of Collection.	After keeping.							
					Oxygen.	Oxygen.	Loss of Oxygen.	Carbonic Anhydride.	Nitrogen.	Free Ammonia.	Albd. Ammonia.	Free Ammonia :	Albd. Ammonia.
1	About 50 yds. E. of shoot (Surface sample)	1.40 p.m.	13·1	18·84	—	5·39* (v)	—	—	—	0·013*	0·020*	1	1·5
2	Same position as 1 (Bottom sample)	1.50 „	13·1	18·86	—	5·47 (v)	—	—	—	0·014*	0·033*	1	2 3
3	Just off shoot—(Surface sample) -	3. 0 „	14·15	18·54	—	0·65*	—	53·09*	11·29*	0·099*	0·041	1	0·4
4	In track of Floats started from shoot at 3 p.m. water turbid (Surface sample)	4.50 „	14·5	18·24	3·25	0·14*	3·11	—	—	0·105*	0·086*	1	0·8
5	In track of Floats—water turbid (Surface sample)	5.30 „	14·5	18·40	3·33	0·28*	3·05	—	—	0·079	0·069	1	0·8
6	In track of Floats—water clearer (Surface sample)	6.30 „	14·3	18·58	3·83 (more than)	0·36†	3·47	—	—	0·075†	0·036*	1	0·5
7	Off Cultra, 50 yds. from shore (Surface sample), water clear.	7.20 „	13·1	19·20	6·55^s	7·13^s*	?	43·36*	11·30*	0·0033†	0·015†	1	4·5
8	Mid Channel—between 1 and 2 buoys (Surface sample), water clear.	7.45 „	12·6	19·22	6·35^s†	6·03^s†	0·52	45·64†	11·42†	0·0046†	0·013†	1	2·8
9	With Floats near 10 buoy (Surface sample)	9. 0 „	13·95	18·60	3·78	1·89	1·88	—	—	0·059†	0·029†	1	0·5
10	In Lagan—2,000 ft. from end of twin. with Floats (Surface sample)	10. 0 „	13·85	18·62	3·69	2·16†	1·53	51·74†	11·48†	0·058†	0·022†	1	0·4

* Analysed June 8th, † Analysed Jnne 9th. ^{s} Supersaturated.

BACTERIOLOGICAL EXAMINATION

No.	1 Total number of Bacteria in 1 c.c. capable of growing on		2 Number of Gas forming Microbes in 1 c.c.					3 Number of B. Coli in 1 cc.						4 Chief biological characters of strain of B. Coli isolated from quantity specified in Col. 3.						5 Bacillus enteritidis sporogenes test.			
	Gelatine at 22° c.	Agar at 37° c.	0·2 5 cc.	1 1 cc.	10 ·1 cc.	100 ·01 cc.	1,000 ·001 cc.	0·02 50 cc.	2 5 cc.	1 1 cc.	10 ·1 cc.	100 ·01 cc.	1,000 ·001 c.c.	Morphology (motile and gram negative).	Gelatine. (characteristic non-liquefying growth).	Gas. (glucose broth, 24 hrs. at 37° c).	Milk Cultures (5 days at 37°c). Acidity.	Milk Cultures (5 days at 37°c). Clot.	Indol (peptone water, 5 days at 37° c).	0·2 5 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.
1	790	30	+	+	–	–	–			+	–	–	–	+	+	+	+	+	+	–	–	–	–
2	640	90	+	–	–	–	–		+	–	–	–	–	+	+	+	+	–	–	–	–	–	–
3	6,500	2,540	+	+	+	+	–					+	–	+	+	+	+	+	–	–	–	–	–
4	15,500	4,500	+	+	+	+	+						+	+	+	+	+	+	+	–	–	–	–
5	35,500	2,535	+	+	+	+	+						+	+	+	+	+	–		+	–	–	–
6	8,600	675	+	+	+	+	–					+	–	+	+	+	+	+	+	–	–	–	–
7	105	20	–	–	–	–	–	?	–	–	–	–	–	·	·	·	·	·	·	–	–	–	–
8	370	14	–	–	+	–	–	?	–	–	–	–	–	·	·	·	·	·	·	–	–	–	–
9	4,000	445	+	+	+	–	+				+	–	+	+	+	+	+	+	+	–	–	–	–
10	3,000	390	+	+	+	–	–				+	–	–	+	+	+	+	+	–	–	–	–	–

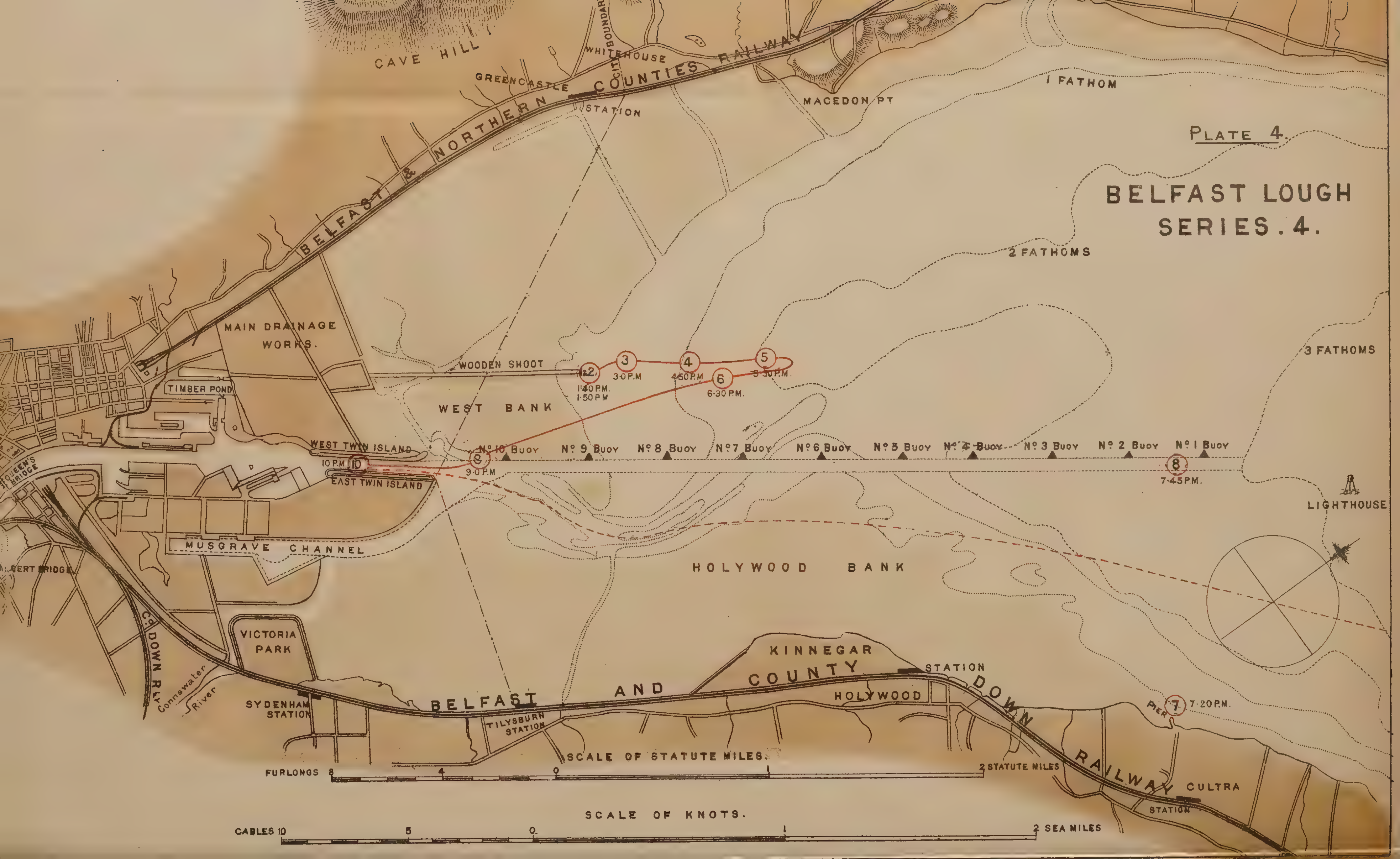


PLATE 4.

BELFAST LOUGH
SERIES. 4.

SERIES 4.

A set of four floats was started at the mouth of the shoot at about the time of high water, but they showed very little drift during three hours. Meanwhile Nos. 1 and 2 were collected at the mouth of the shoot.

The movements of the seagulls appeared to indicate that the floats were in advance of the sewage, and it was therefore decided to pick up the floats and to restart them at half ebb at the mouth of the shoot. This was accordingly done and on the way back numbers of gulls and abundance of floating sewage *débris* were passed. No. 3 sample was collected practically at the period of half ebb, and when the floats were again set adrift at the mouth of the shoot.

Samples 4, 5, and 6 were collected in the track of the floats then started.

It was now past the time of high water, and as it had been decided to watch the movements of the floats during the night, and the men who were to do this were at Cultra, the yacht steamed to that place, where No. 7 was collected. After which, in order to get further information regarding the character of the water entering the Lough on the flood tide No. 8 was collected in the dredged channel.

After this the floats were again located, and Nos. 9 and 10 collected in their track

Chemical Examination.

Pollution.—Nos. 1 and 2 are distinctly polluted, but it seems evident from the samples collected later that the main sewage flow had not reached the end of the shoot when these were taken. The ratio of free to albuminoid ammonia is, roughly, as 1 : 2, indicating possibly that the water had been in contact with the *ulva*, and that free ammonia had been removed.

No. 3, taken at about half ebb, shows from its analysis that probably at this time the main sewage flow had reached the end of the shoot. Nos. 4, 5, and 6 were evidently collected in the sewage current, although the ratio of free to albuminoid ammonia is, in the two first of these, not quite the sewage ratio. No. 4 is interesting as being more highly polluted than No. 3, although collected farther from the shoot. As the wind was easterly, and therefore against the tide, it is possible that the floats were thereby retarded, and that the greatest strength of sewage was a little behind them when they were started. It will be noticed that the albuminoid ammonia in No. 4 is twice as great as in No. 3. In No. 5 the ratio of free to albuminoid ammonia is the same as in No. 4, but dilution was evidently occurring. In No. 6 a remarkable diminution in the albuminoid ammonia has occurred, while the free ammonia has scarcely decreased. The ratio between the two is now again practically the sewage ratio. In No. 9, taken from the neighbourhood of the floats, where the latter were next located, both the free and albuminoid ammonia have decreased considerably, but the ratio between them is still that of sewage. No. 10 is similar in character to No. 9.

General conclusions with regard to the samples collected in the path of the floats.—On the whole the analyses appear to show—if the amount of free ammonia be considered as the index to sewage pollution—that the mixture of sewage and water once having been made moves with the tide without any very rapid dilution occurring. The dilution in No. 3 would correspond, roughly, with 7 of sewage and 23 of water, and the dilution in No. 10 with 7 of sewage and 40 of water.

The Cultra sample (No. 7) is interesting, as it was supersaturated with oxygen (7·13 cc. per litre, even after keeping three days, instead of 6·0, which is the saturation value at the temperature at which the sample was collected). Moreover it contained less free ammonia than the next sample, collected in the channel. Both these results can be explained by the action of the *ulva*, which was present in abundance. On the other hand the albuminoid ammonia is distinctly higher in the Cultra sample than in that collected in the channel, which can also be explained by the action of the *ulva*, as it absorbs ammonia but does not absorb albuminoid matters from a polluted water, and a fair amount of sewage is thrown into the Lough at Cultra.

Temperature.—The extreme variations in temperature amount to 1·9°C., and here again the evidence seems to point to an association of lower temperature in summer with pure water from the Irish Channel, and of higher temperature with the polluted water remaining in the Lough.

The lowest temperature (12·6°) was found in the channel (No. 8) when the flood tide had been running for nearly two hours, while the highest temperature (14·5°) was observed in the most polluted samples (Nos. 4 and 5).

The fairly low temperature of the Cultra sample, probably indicated that a certain amount of pure sea water had reached that place as the flood tide had been streaming in for two hours, and the similar temperature observed near the shoot, where Nos. 1 and 2 were collected may also be explained by flood water which had scarcely begun to move (as the floats indicated) two hours after the ebb had set in.

Salinity.—On the whole the extent of salinity corresponds with relatively low temperature and therefore with pure sea water.

Bacteriological Examination.

Nos. 1 and 2. The results of both the chemical and bacteriological methods of examination are in fair agreement. Both show that the samples were, on the whole, similar in character, and that in spite of the locality from which they were collected, they were not excessively polluted.

No. 3. Here again the results of both methods are in agreement, both showing an extensive increase in pollution.

No. 4. Both methods are also in harmony in showing a further increase in pollution.

No. 5. Here the results of the two methods are different—the chemical showing a *decrease* in pollution (practically in all the factors), while the bacteriological examination shows an *increase* except in the number of organisms developing on the agar medium.

No. 6. Chemically a distinct fall in albuminoid ammonia, while the free ammonia is not very different from No. 5. Bacteriologically an immense fall in the numbers of organisms and also a diminution in *B. coli.*

Nos. 9 and 10. Both methods are in agreement indicating distinct pollution, but somewhat less than in No. 6.

No. 7. This sample contained the lowest proportion of free ammonia in the series, and the other analytical figures indicate that it was fairly pure. The bacteriological examination supports this view.

No. 8 contained more free ammonia but less albuminoid ammonia than the last sample, and a distinct though slight loss of oxygen on keeping. The bacteriological examination shows a greater number of organisms in gelatine medium, but rather fewer in agar. On the whole, then, the results of both methods of examination are in harmony.

BELFAST LOUGH—FIFTH SERIES.

SAMPLES collected June 12th, H.W. 5.52 a.m
(NEAP TIDE).

WATER SAMPLES.

CHEMICAL EXAMINATION.

No.	Where Sample was Collected.	Time.	Temp. °C.	Chlorine (Parts per 1,000)	Dissolved Gases (c.c. per Litre at N.T.P.)					Nitrogen (parts per 100,000) as :—		Ratio.
					At time of Collection.	After keeping.						
					Oxygen.	Oxygen.	Loss of Oxygen.	Carbonic Anhydride.	Nitrogen.	Free Ammonia.	Albd. Ammonia.	Free Ammonia : Albd. Ammonia.
1	At mouth of shoot (Surface sample) -	9.0 a.m.	15·35	18·40	3·08	0·0†	3·08	53·52†	11·07	0·086	0·072	1 : 0·9
	A.											
1A	In track of 1st Floats (Surface sample)	10.15 ,,	14·90	—	—	—	—	—	—	—	—	——
2A	,, ,, ,, ,,	12. 0 ,,	15·50	19·00	(more than) 6·69[s]	5·89†	0·80	45·73†	10·84	0·004	0·023	1 : 6·0
3A	,, ,, ,, ,,	2.55 p.m.	17·45	19·12	4·94	4·03‡	0·91	—	—	0·016	0·023	1 : 1·4
4A	,, ,, ,, ,,	6.20 ,,	19·60	18·52	2·42	0·00‡	2·42	57·60‡	10·26	0·132	0·046	1 : 0·3
	B.											
2	In track of 2nd Floats (Surface sample)	10.45 a.m.	15·85	18·56	2·79	0·28†	2·51	—	—	0·099	0·062	1 : 0·6
3*	,, ,, ,, ,,	12.45 p.m.	16·80	18·80	3·78	2·72†	1·06	—	—	0·082	0·032	1 : 0·4
4	,, ,, ,, ,,	4.10 ,,	17·25	18·88	4·61	2·51‡	2·10	50·85‡	11·02	0·069	0·028	1 : 0·4
5	,, ,, ,, ,,	6.40 ,,	16·20	18·70	4·36	2·80‡	1·56	—	—	0·049	0·031	1 : 0·6

A. First set of Floats started at shoot 6.30 a.m.
B. Second ,, ,, ,, 9.0 a.m.
* Taken where Floats probably were at 12.0 a.m.

† Analysed June 15th.
‡ ,, ,, 16th.
[s] Supersaturated with oxygen.

BACTERIOLOGICAL EXAMINATION.

Sample Number.	1. Total No. of Bacteria in 1 c.c. capable of growing on		2. Number of Gas-forming Microbes in 1 c.c.						3. Number of B. Coli in 1 c.c						4. Chief biological characters of the strain of B. Coli isolated from the quantity specified in Col. 3.						5. Bacillus enteritidis sporogenes test.				6. Number of streptococci in 1 c.c.					
	Gelatine at 22° c.	Agar at 37° c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	10,000 ·0001 c.c.	·02 50 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	Morphology, (motile & gram negative).	Gelatine (characteristic non-liquefying growth.)	Gas (glucose Broth, 24 hours at 37° c.)	Milk Cultures (5 days at 37° c.) Acidity.	Milk Cultures (5 days at 37° c.) Clot.	Indol (peptone water 5 days at 37° c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	10,000 ·0001 c.c.
1	207,200	11,600	+	+	+	+	-	-					+	-	+	+	+	+	-	-	-	-	-	-	?	?	+	-	-	-
2	47,900	700	+	+	+	+	-	-					+	-	+	+	+	+	+	+	-	-	-	-	+	?	?	-	-	-
3	2,100	300	+	+	-	-	-	-	+	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-	+	-	-	-	-	-
4	4,320,000	260,000	+	+	+?	-	-	-				+	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
5	1,700	1,100	+	+	+	+?	-	-				+	-	-	+	+	+	+	+	+	-	-	-	-	?	?	+	-	-	-
2a	2,000	200	+	-	-	-	-	-	+	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-
3a	700	100	+	+	+	-	-	-				+	-	-	+	+	+	+	-	-	-	-	-	-	+	+	-	-	-	-
4a	5,400	1,700	+	+	+	+	-	-					+	-	+	+	+	+	+	+	-	-	-	-	+	?	?	-	-	-

BELFAST LOUGH—FIFTH SERIES.

DREDGINGS.

CHEMICAL EXAMINATION.

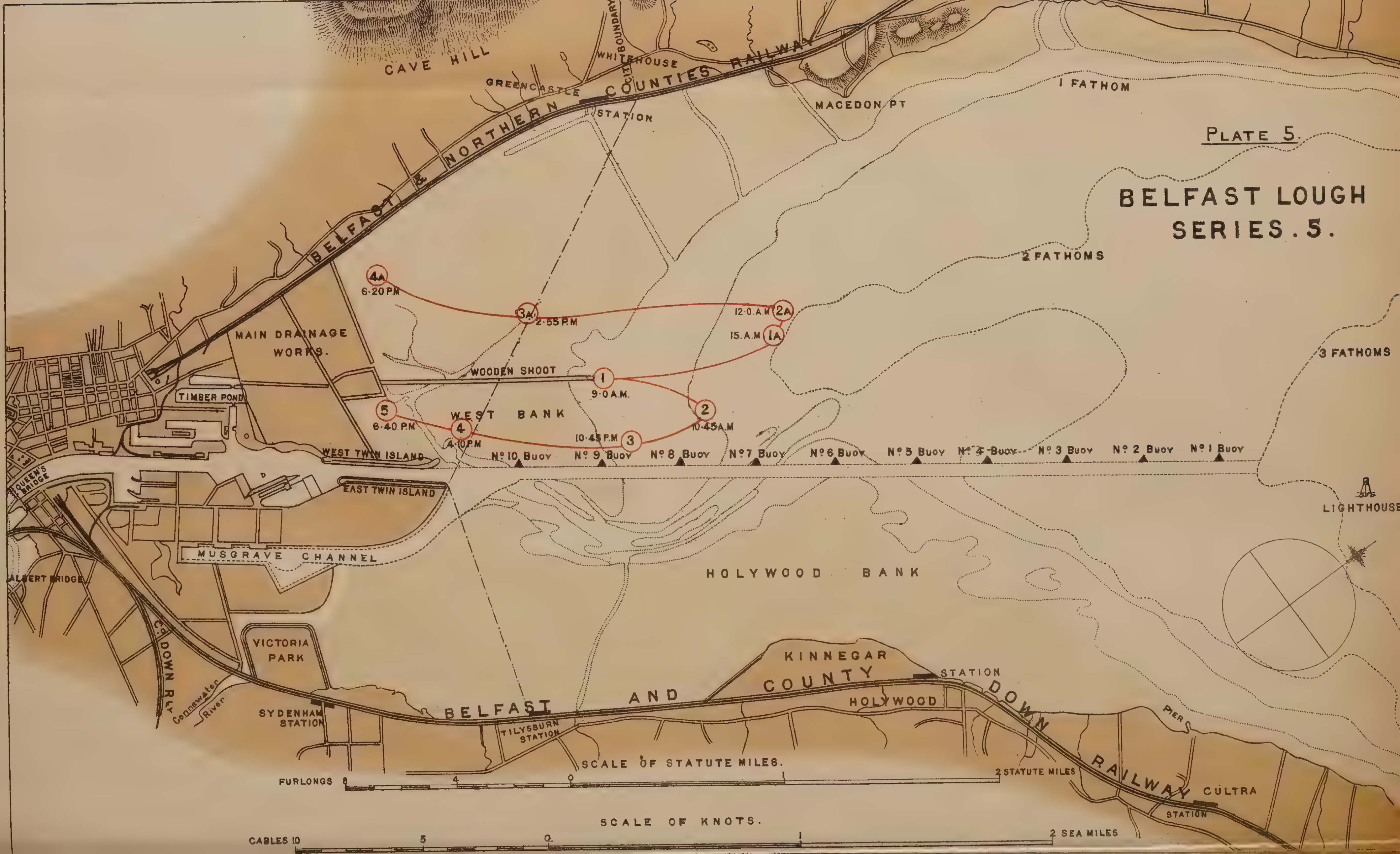
No.	Where Sample was Collected.	Percentage loss on Ignition.	Percentage of Nitrogen.	Probable percentage of Sewage Sludge.	Remarks.
1	At mouth of shoot - -	1·76	0·055	1·55	Black sand. Stinking. Contained some green seaweed. On igniting blackened and emitted vapours.
	A.				
1	In track of 1st floats - -				—
2	" " - -	5·00	0·130	4·3	Grey mud. Stinking somewhat. On keeping blackened. On igniting blackened and emitted slight vapours.
3	" " - -	2·80	0·525	18·9	Grey mud with black patches. Stinking. On keeping all blackened. Contained shells, small crabs and green seaweed. On igniting blackened and emitted vapours.
4	" " - -	8·01	0·261	9·2	Black mud. Stinking. Contained green seaweed. On igniting blackened and emitted vapours.
	B.				
2	In track of 2nd floats - -	6·99	0·205	7·1	Black mud. Stinking. On igniting blackened and emitted vapours.
3	" " - -	5·94	0·199	6·9	" " " "
4	" " - -	12·93	0·129	4·3	" " " "
5	" " - -	12·42	0·478	17·2	" " Contained many small worms.

BACTERIOLOGICAL EXAMINATION.

Sample Number.	1. Total number of Bacteria in 1 gm capable of growing on		2. Numbers of Gas-forming Microbes in 1 gm.						3. Number of B. Coli. in 1 gm.					4. Chief biological characters of the strain of B. Coli. isolated from the quantity specified in Col. 3.						5. Bacillus enteritidis sporogenes test.				6. Number of streptococci in 1 gm.					
	Gelatine at 22° c.	Agar at 37° c.	10 ·1 gm.	100 ·01 gm.	1,000 ·001 gm.	10,000 ·0001 gm.	100,000 ·00001 gm.	1,000,000 ·000001 gm.	10 ·1 gm.	100 ·01 gm.	1,000 ·001 gm.	10,000 ·0001 gm.	100,000 ·00001 gm.	Morphology (motile and gram negative).	Gelatine (characteristic non-liquefying growth).	Gas (glucose broth 24 hours at 37° c.).	Milk Cultures (5 days at 37° c.) Acidity.	Milk Cultures (5 days at 37° c.) Clot.	Indol (peptone water 5 days at 37° c.).	0·2 5 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.	1,000 ·001 gm.	10,000 ·0001 gm.	1,000,000 ·000001 gm.
1	270,000,000	47,000,000	+	+	+	+	–	–				+	–	+	+	+	+	–	+	+	+	+	–	+	+	–	–	–	–
2A	67,380,000	5,564,000	+	+	+	+	+	–					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3A	9,044,600	606,840	+	+	+	+	–	–				+	–	+	+	+	+	+	+	+	+	+	+	+	?	?	–	–	–
4A	63,456,000	3,866,000	+	+	+	+	–	–				+	–	+	+	+	+	–	–	+	+	+	+	–	–	–	–	–	–
2	4,998,000	1,230,800	+	+	+	+	–	–			+	–	–	+	+	+	+	–	–	+	+	+	+?	+	+	+	?	?	–
3	9,744,780	2,065,000	+	+	+	–	–	–			+	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–
4	2,790,000	303,400	+	+	–	–	–	–		+	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	–
5	151,830,000	12,290,000	+	+	+	+	+	–					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	?

PLATE 5.

BELFAST LOUGH SERIES. 5.



SERIES 5.

Several different objects were aimed at in this series. One of these was to ascertain to what extent the flow of the sewage current in the Lough would be modified by a neap as contrasted with a spring tide, another to trace the direction of the sewage current during the earlier and later hours of the ebb respectively, while a third was the examination of the bed of the Lough at those places where the water samples were collected. For the latter purpose a small dredge was employed which is described at p. 225, and which proved very serviceable.

Two sets of floats were started from the shoot: the first about half an hour after high water (No. 7 set) and the second at half ebb (No. 2 set). Each of these sets was attended by a rowing boat, while the steam yacht from which the samples were collected and the position of the floats determined, cruised as occasion demanded from one set of floats to the other.

On this day the flow of sewage did not manifest itself at any time by a considerable amount of floating matters. The sea-gulls (so useful an index on such occasions) being chiefly busy between the pumping station and the mouth of the shoot, and on rowing to the spot where they had collected some floating excrement was visible, but not much.*

A fairly fresh easterly breeze was blowing, which no doubt had some effect on the floats.

Chemical Examinations.

Water samples collected in the track of the first set of floats. The movement of this set of floats was so sluggish that no samples were collected in their track until the commencement of the 5th hour of the ebb, (No. 1A). Before this, however, a sample was collected at the mouth of the shoot towards the end of the 3rd hour of the ebb (No. 1). No further attention could be given to the first set of floats until nearly low tide, when 2A was collected. The two later samples, 3A and 4A, were taken respectively at about half flood and high tide.

Pollution. No. 2A was fairly pure as indicated by the free ammonia, but contained a fair proportion of albuminoid ammonia. The ratio between the two is nearly that obtaining in pure sea water, though the actual quantities are about four times as high. This sample was distinctly supersaturated with oxygen when collected, and even after keeping for three days was still supersaturated, although a distinct loss of oxygen had occurred at the end of that time. We can suggest no other explanation for this supersaturation with oxygen than that already given in similar cases, namely, the action of *ulva.*

3A. Shows a considerable increase in free ammonia without change in the amount of albuminoid ammonia, thus materially altering the ratio between the two. There was also a considerable diminution in dissolved oxygen. The pollution therefore had clearly increased.

4A. From all the analytical factors extensive increase in pollution is indicated.

Water Samples collected in the Track of the Second Set of Floats.

Pollution. No. 1, though not exactly belonging to this set of samples, is related to them. In it distinct pollution is indicated by the quantities of free and albuminoid ammonia, the low proportion of oxygen when collected, and the total disappearance of this on keeping.

Nos. 3, 4 and 5 show a gradual diminution in free ammonia, and with the exception of the last a gradual decrease in albuminoid ammonia also. The ratio between these two is in all four samples either the sewage ratio or closely approximates it. The first three of these samples show a progressive increase in the amount of dissolved oxygen present at the time of collecting, but No. 5 shows a slight decrease in relation to No. 4.

Temperature and Salinity. The variations in the temperature of the samples of this series were considerable, amounting to an extreme of 4·7°. But the correlations between temperature, pollution, and salinity are not so clearly defined in this as in some of the previous series. The samples collected in the track of the first set of floats show a progressive increase in temperature from 14·9 to 19·6. Unfortunately the first was not analysed, but the second had nearly the lowest temperature of the whole series, and it was undoubtedly the purest and nearly the saltest. On the other hand 4A had the highest temperature, and in most of the analytical characteristics was the most impure.

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* It ought to be mentioned that the shoot was out of repair and that at one or two places considerable leakages of sewage occurred.

In the case, however, of the samples collected in the track of the second set of floats, in the first three there is a progressive rise in temperature and a *diminution* in impurity, while the salinity *increases.* In No. 5 there is a fall both in temperature and salinity, while the diminution in impurity continued.

Bacteriological Examination.

Water samples collected in the track of the first set of floats.—No. 2A. Some pollution, but not extensive, indicated by the total numbers of organisms, and *B. coli* was present but not extensively. Chemically, this was the purest sample of the series and quite different in character from No. 3. Bacteriologically, however, the samples taken as a whole resembles the latter.

3A. So far as the total numbers of organisms are concerned in both gelatine and agar media, this was the purest sample of the series but in other respects it was not so. Thus *B. coli* were abundant and *streptococci* were also present.

4A. Contained a larger number of organisms than the preceding sample, but that number is not excessive. *B. coli* were, however, abundant and probably *streptococci* also. Chemically this sample was *probably* the most polluted of the series.

Water samples collected in the track of the second set of floats.—No. 1. High pollution indicated by the total number of organisms, both in gelatine and agar media and also by the number of *B. coli*. *Streptococci* also possibly present.

No. 2. A great reduction in the numbers of organisms when compared with No. 1 (about $\frac{1}{4}$–$\frac{1}{5}$ in the gelatine medium and about $\frac{1}{16}$ in the agar medium). *B. coli* and *streptococci* are, however, quite as numerous as in No. 1.

No. 3. Again a considerable reduction in the total numbers of organisms in both media, and also a considerable reduction in the number of *B. coli*. But *streptococci* were still present.

No. 4. In Nos. 1, 2 and 3 there are on the whole no violent discrepancies between the results of the bacteriological and chemical methods of examination, but in No. 4 there is such, as the total numbers of organisms in the two culture media increased to an enormous extent and the *B. coli* have also run up but not to a corresponding degree. *Streptococci* are, however, absent.

No. 5 shows a remarkable diminution in the total numbers of organisms in both media, compared with the last sample, but *B. coli* has not diminished and *streptococci* were perhaps present.

BELFAST LOUGH—SIXTH SERIES.

SAMPLES collected July 6th on a line between Holywood and Macedon point, H.W., 12.43 a.m.

(SPRING TIDE.)

Wind light from E.S.E. and later calm.

WATER SAMPLES.

CHEMICAL EXAMINATION.

No.	Where Sample was Collected.	Time.	Temp. °C.	Chlorine.	Dissolved Gases (c.c. per Litre at N.T.P.)					Nitrogen (Parts per 100,000) as :—		Ratio.
					At time of collection.	After keeping.						
				Parts per 1,000.	Oxygen.	Oxygen.	Loss of Oxygen.	Carbonic Anhydride.	Nitrogen.	Free Ammonia.	Albd. Ammonia.	Free Ammonia : Albd Ammonia.
1	S. side (400 yds. from Holywood) -	3.30	16·60	18·80	5·47	5·18	0·29	47·71	10·82	0·0296	0·0214	1 : 0·7
2	,, (330 ,, ,, Channel) -	5. 0	16·30	19·90	5·94	5·22	0·72	—	—	0·0132	0·0231	1 : 1·7
3	,, (In Channel near No. 5 Buoy)	5.15	16·10	18·90	5·71	5·15	0·56	47·55	10·90	0·0198	0·0263	1 : 1·3
4	About middle of Lough - - -	6. 0	16·00	18·78	4·75	3·55	1·20	—	—	0·0379	0·0230	1 : 0·6
5	N. side (1,400 yds. from Channel) -	6.45	16·45	18·80	4·25	2·34	1·91	50·66	10·90	0·0527	0·0296	1 : 0·6
6	,, (2,150 ,, ,, ,,) -	7.10	16·30	18·96	5·83	4·78	1·05	—	—	0·0165	0·0280	1 : 1·7
7	,, (Macedon Point 200 yds. from shore).	7.55	15·25	19·40	6·14 ^{s}	5·93 ^{s}	0·21	44·70	10·82	0·0016	0·0181	1 : 11·0
8	S. side (600 yds. off Kinnegar) -	8.40	16·80	18·76	6·78 ? ^{s}	6·61 ^{s}	0·17	—	—	0·0165	0·0230	1 : 1·4

^{s} supersaturated.

BACTERIOLOGICAL EXAMINATION.

Sample Number.	1. Total number of Bacteria in 1 c.c. capable of growing on		2. Number of Gas-forming Microbes in 1 c.c.						3. Number of B. Coli in 1 c.c.						4. Chief biological characters of the strain B. Coli isolated from the quantity specified in Col. 3.						5. Bacillus enteritidis sporogenes test.			
	Gelatine at 22° c.	Agar at 37° c.	·0 100 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	·01 100 c.c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.	1,000 ·001 c.c.	Morphology (motile and gram negative).	Gelatine (characteristic non-liquefying growth).	Gas (glucose broth, 24 hours at 37° c.).	Milk Cultures (5 days at 37° c.).		Indol. (peptone water, 5 days at 37° c.	·1 10 c.c.	1 1 c.c.	10 ·1 c.c.	100 ·01 c.c.
																		Acidity.	Clot.					
1	500	198	+	-	-	-	-	-	+	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-
2	100	45	+	-	-	-	-	-	+	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-
3	400	105	+	-	-	-	-	-	+	-	-	-	-	-	+	+	+	+	-	+	-	-	-	-
4	400	106	+	+	+	-	-	-	+	+	+	-	-	-	+	+	+	+	+	+	-	-	-	-
5	1,200	326	+	+	+	+	-	-	+	+	+	+	-	-	+	+	+	+	+	+	+	-	-	-
6	1,000	152	+	-	-	-	-	-	+	-	-	-	-	-	+	+	+	+	+	-	-	-	-	-
7	1,200	94	+	+	+	-	-	-	+	+	+	-	-	-	+	+	+	+	-	-	-	-	-	-
8	100	87	+	-	+	-	-	-	+	-	-	-	-	-	+	+	+	+	+	+	-	-	-	-

DREDGINGS.

CHEMICAL EXAMINATION.

No.	Where Sample was Collected.	Per cent. Loss on Ignition.	Percentage of Nitrogen.	Probable percentage of Sewage Sludge.	Remarks.	
1 - -	S. side (400 yards from Holywood) - - -	0·85	0·016	0·1	Grey Sand	On keeping, some minute black patches. On igniting, blackened. But no visible vapours.
2 - -	,, (300 yards from Channel) - - - -	0·83	0·016	0·1	,, ,,	Ditto. Ditto.
3 - -	,, (in Channel near No. 5 Buoy) - - -	4·81	0·103	3·3	Dark Grey Mud	Blackened. Ditto. But some visible vapour.
4 - -	About middle of Lough - - - - -	2·28	0·066	2·0	,, ,, ,	Ditto. Contained minute crustacea. Ditto. Vapour scarcely visible.
5 - -	N. side (1,400 yards from Channel) - - -	2·48	0·064	1·9	,, ,, ,,	Ditto. Contained minute crustacea. Ditto. Vapour scarcely visible.
6 - -	,, (2,150 yards from Channel) - -	4·96	0·119	3·9	,, ,, ,,	Ditto. Contained minute crustacea. Ditto. Some visible vapour.
7 - -	,, (Macedon Point, 200 yards from shore) -	1·12	0·027	0·5	Fine Grey Sand	Ditto. On igniting, scarcely blackened.
8 - -	S. side (600 yards from Kinnegar) - - - -	0·69	0·017	0·1	Coarse ,, ,,	On keeping, not blackened. On igniting, scarcely blackened.

BACTERIOLOGICAL EXAMINATION.

Sample Number.	1. Total number of Bacteria in 1 gm. capable of growing on		2. Number of B. Coli in 1 gm.						3. Chief biological characters of the strain of B. Coli. isolated from the quantity specified in Col. 2.						6. Bacillus enteritidis sporogenes test.			
	Gelatine at 22° c.	Agar at 37° c.	.1 10 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.	1000 ·001 gm.	10,000 ·0001 gm.	Morphology (motile and gram negative).	Gelatine (characteristic non-liquefying growth).	Gas (glucose broth 24 hours at 37° c.	Milk Cultures (5 days at 37° c.).		Indol (peptone water 5 days at 37° c.).	·2 5 gm.	1 1 gm.	10 ·1 gm.	100 ·01 gm.
												Acidity.	Clot.					
1	202,800	9,223			+	—	—	—	+	+	+	+	+	+	+	+	—	—
2	358,500	4,892		+	—	—	—	—	+	+	+	+	+	+	+	+	—	—
3	5,070,000	216,000			+	—	—	—	+	+	+	+	+	+	+	+	+	—
4	53,950,000	4,363,000						+	+	+	+	+	+	+	+	+	+	+
5	69,110,000	3,276,000				+	—	—	+	+	+	+	+	+	+	+	+	—
6	490,200	306,400				+	—	—	+	+	+	+	—	+	+	+	+	—
7	11,036,000	2,616,000			+	—	—	—	+	+	+	+	+	+	+	+	+	+
8	461,130	3,290			+	—	—	—	+	+	+	+	—	—	?	—	—	—

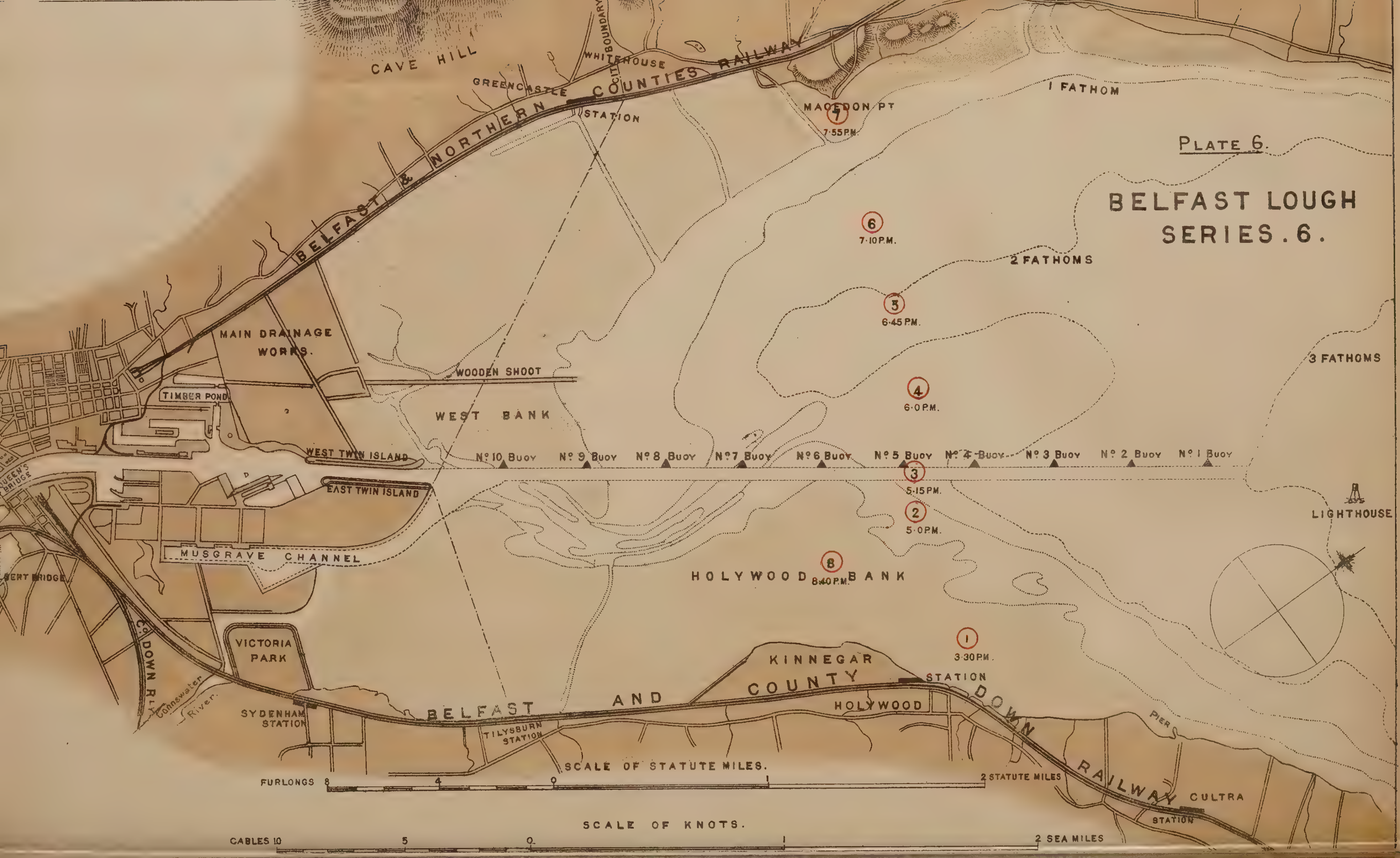

PLATE 6.

BELFAST LOUGH
SERIES. 6.

SERIES 6.

The main object of this series was to investigate both the water and bed of the Lough from shore to shore in its upper reaches, and had it been possible we should have collected all the water samples simultaneously so as to gain an idea of their relative condition at a given state of the tide. But as this was not feasible, the samples were collected as rapidly as possible from a steam yacht. It will be seen, however, from the table of results that this took about five hours to accomplish, so that tidal effects cannot be ignored in considering the analysis.

For reasons which need not here be specified the samples were as far as possible collected at equal distances along an imaginary straight line stretching from Holywood on the south side to Macedon Point, which is nearly opposite, on the north side.

Chemical Examination.

Pollution.—No. 1 sample is apparently distinctly but not highly polluted. The ratio of free to albuminoid ammonia approximates the sewage ratio.

No. 2. Less free ammonia, but a trifle more albuminoid ammonia than in the last sample, leading to a very distinct change in the ratio of the two. Also more dissolved oxygen in the sample when collected, but, on the other hand, more of this latter was lost on keeping than in the case of No. 1.

No. 3. A slight but distinct increase in pollution.

No. 4. Again an increase of pollution, but now of a much more decided kind, in all the factors. The ratio between the free and albuminoid ammonia now becoming the sewage ratio.

No. 5. The results point to a still further increase in pollution in all the factors.

No. 6. The free ammonia is much less than in Nos. 3, 4, and 5, but the albuminoid ammonia is still high, and the loss in dissolved oxygen on keeping the sample was considerable. The sample is thus shown to be still distincly polluted.

No. 7. This sample is in striking contrast to all the others. It was supersaturated with dissolved oxygen, and only traces of free ammonia were present. But, on the other hand. it contained a fair amount of albuminoid ammonia (not so very different from the samples distinctly polluted with sewage) and as a consequence the ratio between free and albuminoid ammonia is remarkable.

An abundance of the *ulva* was growing close to the spot where this sample was collected, which possibly affords an explanation.

No. 8. It should be noted that this sample was collected on the opposite side of the Lough as regards the last sample. It is chiefly of interest on account of the high proportion of dissolved oxygen it contained, it having been supersaturated not only when collected but also after keeping

Temperature.—The temperature in most of the samples was fairly constant, varying between 16·0 and 16·8°. Among these the samples with the highest temperatures (*i.e.*, No. 1, T = 16·6, and No. 8, T = 16·8) are those which were collected inshore. No doubt this was caused as already mentioned by the warming effect (on the water) of the sandbanks exposed to the sun at low tide. In support of this explanation it will be seen that the sample having the highest temperature was the latest to be collected (8.40 p.m.).

One sample (No. 7) was characterised by a temperature (15·27°) distinctly lower than that of the others. This sample, as already stated, was entirely different in its chemical characters from all the others.

Salinity. The salinity of all the samples, with the exception of the last referred to, showed only a slight variation (18·76 to 19·00 chlorine per 1,000). In No. 7, however, the salinity is distinctly higher (19·40), thus confirming the view that in summer a lower temperature is associated with the (relatively) cool stream of pure ocean water, and as a consequence with purity.

Bacteriological Examination.

No. 1 does not contain a large number of organisms, but *B. coli* were present. On the whole the bacteriological examination agrees with the chemical in showing distinct but not high pollution.

No. 2 shows distinctly less pollution than No. 1 so far as the total number of organisms are concerned, but *B. coli* were present to the the same extent.

No. 3. In this sample there is a rise in the total numbers of organisms, but *B. coli* were present as before. The chemical examinations showed a slight but distinct increase in pollution.

No. 4. Here there was practically no increase in the number of organisms, but on the other hand there was a very considerable increase in the number of *B. coli.*

No. 5. The results of the bacteriological examination of this sample are in harmony with those of the chemical, in showing a decided increase of pollution in all the analytical factors. *B. enteritidis sporogenes* was found for the only time in the series.

No. 6. Shows a sudden drop in the number of *B. coli*; the decrease in the total number of organisms, however, is not very marked. Chemically the sample contained much less free ammonia than 3, 4 or 5.

No. 7. The results of the bacteriological examination are in striking contrast with those of the chemical in two directions. There were more organisms in the gelatine medium than in the last sample, and a very decided rise in *B. coli*; but on the other hand there was a marked diminution in the number of organisms appearing in the agar medium.

Chemically, this sample was remarkable for the minute quantity of free ammonia which it contained, and it was supersaturated with oxygen, but albuminoid ammonia was present in it in fair quantity.*

No. 8. This sample contained relatively few organisms. Both in its bacteriological and chemical characteristics it resembled No. 2 on the whole, with the exception that, unlike that sample, it was supersaturated with oxygen.

SERIES 5.

Dredgings.

It is obvious from the table of results that all the samples of the series were polluted with sewage sludge, and that in nearly all, the pollution was considerable. The figures indeed indicate that the bed of the Lough in its upper reaches in is a very foul condition and that this region functions at present as a settling bank for the sewage of Belfast. Is the results recorded in the table are compared with those for Dublin Harbour,† the difference between the two sets of figures is very striking. The bed of Dublin Harbour is remarkably free from sewage solids even close to the Rathmines and Pembroke outfall, through which the sewage of a population of 60,000 passes in an untreated condition. This difference in the condition of the two localities can, we believe, be explained in one way only, namely, by the difference in the rapidity of the tidal currents with corresponding differences in scour. In the upper reaches of Belfast Lough as the Float observations indicate, the tides are remarkably sluggish, whereas in Dublin Harbour they are rapid. Consequently in Belfast Lough the sewage solids are deposited in the upper reaches, and probably never gain the open sea, whereas in Dublin Harbour the sewage solids from the Pembroke and Rathmines outfall are apparently either swept out to sea or are rapidly oxidized by the dissolved oxygen in the water streaming over them.

A detailed criticism of the figures obtained in this series at Belfast appears to be unnecessary, but attention may be drawn to No. 1 sample, collected close to the "shoot," which was found to contain the least amount of sewage solids, although it might have been anticipated that it would have contained most. But here again we suggest that the explanation is to be found in the effects of scour, the scouring action in this case being caused by the shoot itself. The suspended matters are probably driven along the bed of the Lough by the sewage current and only come to rest when the latter dies out through friction with the surrounding water.

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* The difference in chemical and bacteriological characteristics can be explained by the action of *ulva.*

† See pp. 278–9.

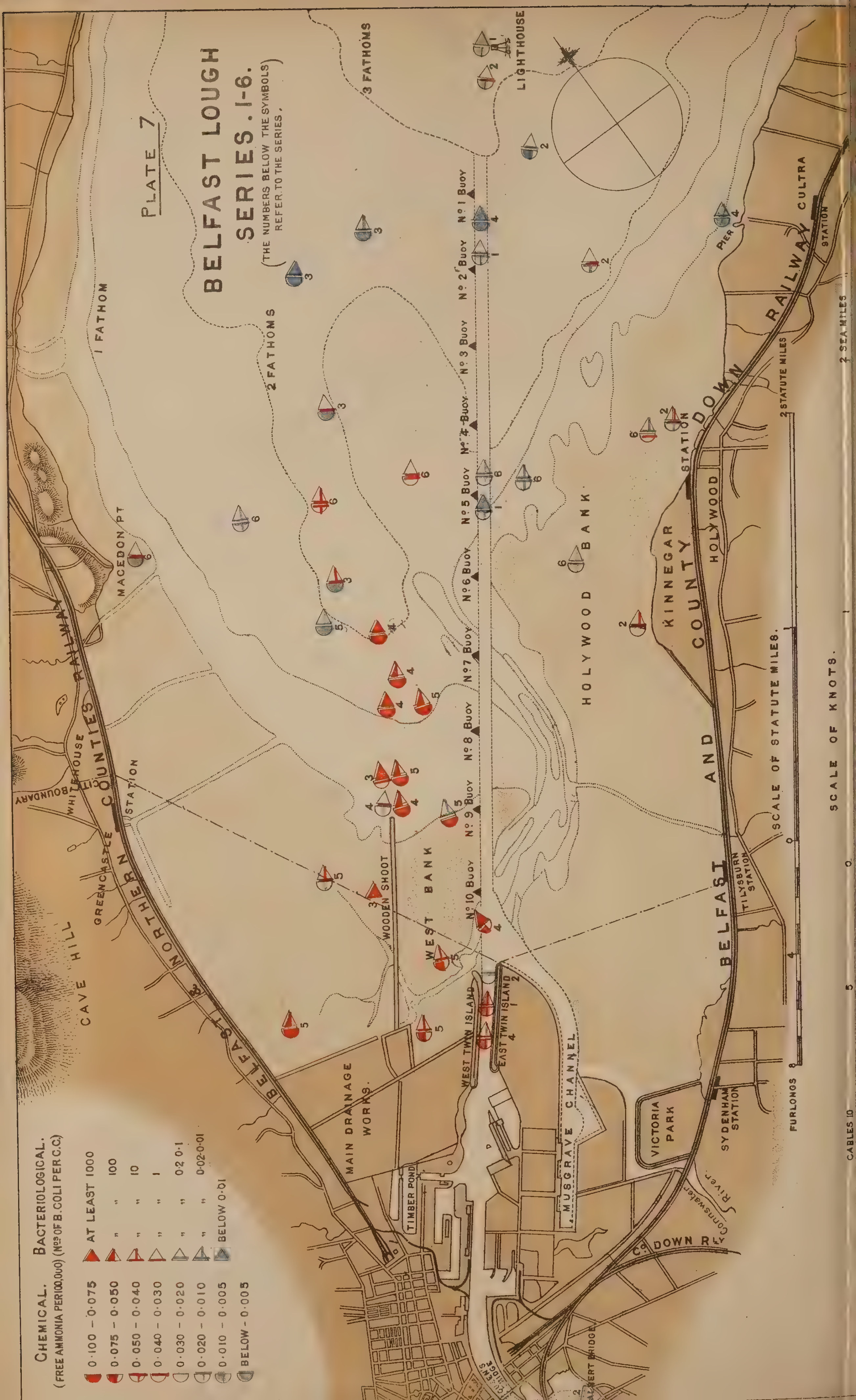
PLATE 7.
BELFAST LOUGH
SERIES. 1-6.
(THE NUMBERS BELOW THE SYMBOLS REFER TO THE SERIES.)
CHEMICAL. (FREE AMMONIA PER 100,000)
BACTERIOLOGICAL. (Nº OF B. COLI PER C.C.)
0·100 - 0·075 AT LEAST 1000
0·075 - 0·050 " 100
0·050 - 0·040 " 10
0·040 - 0·030 " 1
0·030 - 0·020 " 0·2-0·1
0·020 - 0·010 " 0·02-0·01
0·010 - 0·005 BELOW 0·01
BELOW - 0·005
1 FATHOM
2 FATHOMS
3 FATHOMS
LIGHTHOUSE
Nº 1 BUOY
Nº 2 BUOY
Nº 3 BUOY
Nº 4 BUOY
Nº 5 BUOY
Nº 6 BUOY
Nº 7 BUOY
Nº 8 BUOY
Nº 9 BUOY
Nº 10 BUOY
MACEDON PT
WHITEHOUSE
CITY BOUNDARY
GREENCASTLE
STATION
CAVE HILL
BELFAST & NORTHERN COUNTIES RAILWAY
WOODEN SHOOT
WEST BANK
HOLYWOOD BANK
MAIN DRAINAGE WORKS
TIMBER POND
WEST TWIN ISLAND
EAST TWIN ISLAND
MUSGRAVE CHANNEL
VICTORIA PARK
SYDENHAM STATION
TILLYSBURN STATION
KINNEGAR
HOLYWOOD
STATION
PIER
CULTRA STATION
BELFAST AND COUNTY DOWN RAILWAY
Cº DOWN RLY
Connswater River
QUEENS BRIDGE
ALBERT BRIDGE
SCALE OF STATUTE MILES.
SCALE OF KNOTS.
FURLONGS 8 4 0 1 2 STATUTE MILES
CABLES 10 5 0 1 2 SEA MILES

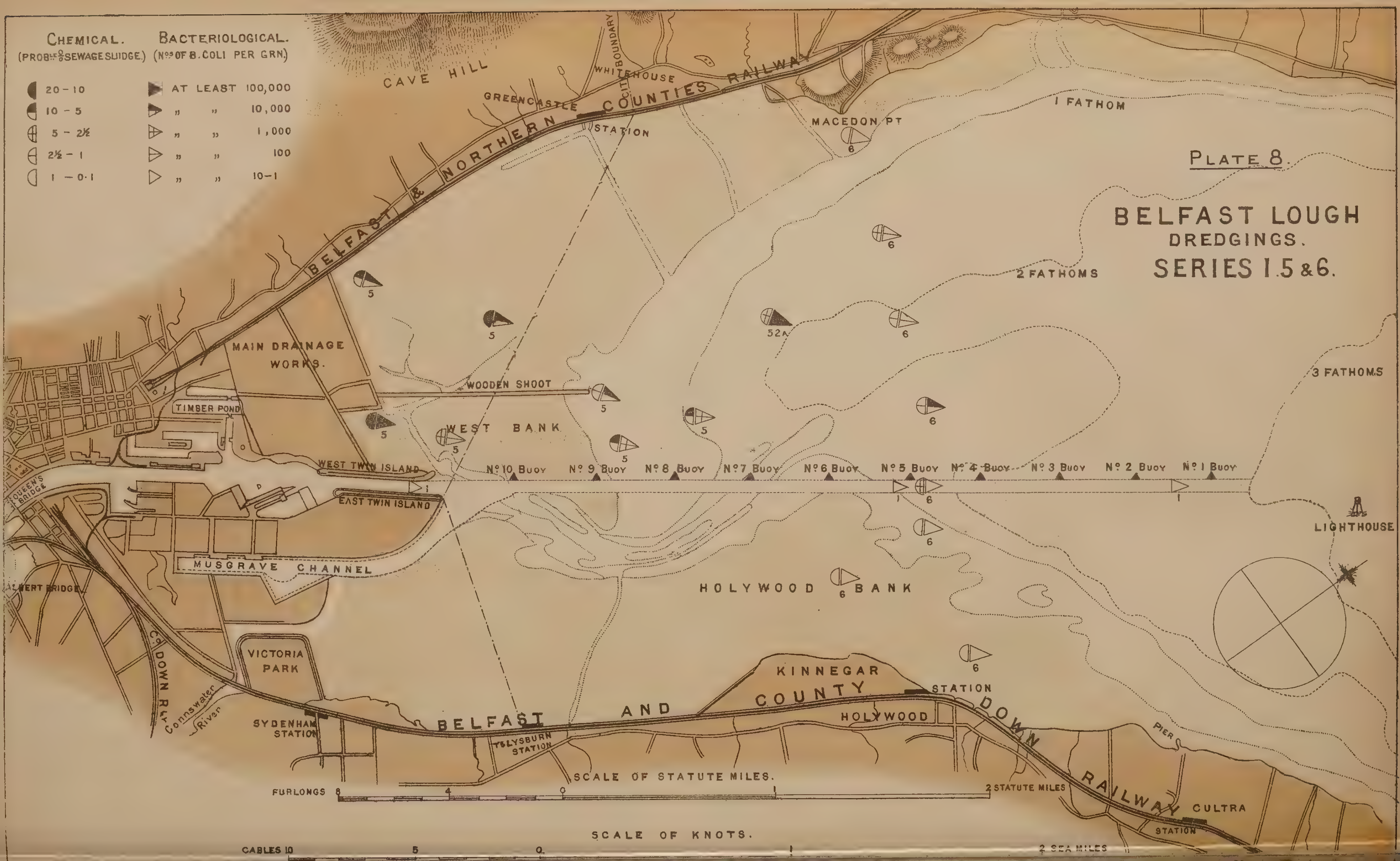
PLATE 8.

BELFAST LOUGH DREDGINGS. SERIES 1.5 & 6.

The condition of the bed of the Lough revealed by the analyses of this series of dredgings is important in relation to the growth of green seaweeds. For, as already stated, the latter derive the nitrogen of their tissues chiefly from ammonia in the water. Hence every effort is being made at Belfast to devise a scheme of sewage purification which shall, as far as possible, get rid of the ammonia and also avoid the production of nitrates, which likewise encourage the growth of the seaweeds. But ammonia is not only present in solution in sewage, but is also evolved from sewage sludge. Hence the very serious question arises: Will the *ulva* nuisance cease in the Lough when the sewage of Belfast and of those districts at present draining into it is adequately purified? Will not the sewage solids on the bed of the Lough (representing, as they no doubt do, accumulations of several years) continue to give off ammonia and so lead to a prolongation of the *ulva* nuisance, until by natural processes the nitrogenous constituents of the silt are fully decomposed?

Special experiments on this point are described on p. 135, which, we are afraid, indicate that the answer to the latter part of this question must be in the affirmative.

SERIES 6.

Dredgings.

Nos. 1 and 2 appear from the chemical analyses to be almost clean sand and to show that the effects of the discharge of the Holywood sewage on the bed of the Lough are practically *nil.*

Nos. 3, 4, 5 and 6. Chemically Nos. 3 and 6 show the highest proportion of sewage solids. While bacteriologically No. 4 is by far the most polluted; further in No. 6, though the *B. coli* and the *B. enteritidis sporogenes* remain unchanged there is a marked fall in the total number of Bacteria.

No. 7. Here, too, the chemical and the bacteriological results fail to agree. According to the former the sample is only slightly polluted while the latter seems to show that it is more polluted even than No. 3.

No. 8 is similar to Nos. 1 and 2.

The zone of pollution as indicated by the *bed* of the Lough along this section would thus appear to extend from the position corresponding with No. 3 to that corresponding with No. 6, whereas the sewage current as indicated by the condition of the *water* in this series does not appear to extend beyond 3 and 4. It must, however, be remembered that a single examination of the water from a given locality in a tidal area can only furnish information regarding its condition at the time of its collection, and that a sample taken an hour or two either earlier or later from the same spot may show a totally different character. On the other hand, the composition of the bed furnishes, to some extent, a record of the condition of the waters above it during a prolonged period.

* * * * *

GENERAL CONCLUSIONS.

The float experiments, the chemical examination both of the water and dredgings, as well as the bacteriological examination of the same samples, all agree in indicating an extensive zone of pollution in the Lough, which probably extends from close to the City to a distance of three or three and a half miles seawards. Our observations have not been sufficient to determine its exact width and more especially its extension (if any) on the south side of the dredged channel: but to the north of the latter its width would appear to be at least a mile and possibly more.

On Plate 7 the results of all the different float observations and examinations of the water samples are given, the latter being represented by a series of symbols, the exact significance of which is explained on the Plate itself. Here it will be sufficient to say that free or saline ammonia has been taken as the chemical index of sewage pollution, the symbol being a semicircle, while the quantity in a given sample is indicated by the extent of red shading within the symbol. On the other hand, when the sample contained but little free ammonia, the increasing purity is shown by the extent of blue shading. A similar idea is carried out as regards the results of the bacteriological examination, *B. coli* being taken as the index of sewage pollution, the symbol being a triangle, while the number of *B. coli* in a given sample is indicated by the extent of red shading within the symbol or if this is small the increasing purity is represented by the extent of the blue shading. On the chart the two symbols are combined for a given sample, so that the results of both methods of examination are seen at a glance.

This chart shows that on the whole the results of the two methods of examination are in harmony, and define with fair distinctness the area of gross pollution on the north side of the dredged channel.

On Plate 8 the results of the examination of the dredgings are given, these being represented by a series of symbols similar to those employed for the water, but with a somewhat different significance—which is explained on the plate itself.

TIDES IN THE UPPER REACHES OF BELFAST LOUGH.

As already stated three sets of float experiments were made (corresponding with 3, 4, and 5 series), the last of which, however, involved two separate sets of floats started at different times.

The first two series of float experiments were made during spring tides, while the last was made during neaps. In the first series the wind was westerly, while in the others it was easterly.

The results of the float experiments may be tabulated as follows :—

Series.	Direction of Wind.	Time when Floats were Started.	Distance Travelled by the Floats :—				Average Speed per hour.	
			Seawards during the Ebb.		Towards Belfast during the Flood.		Ebb. (Knots).	Flood. (Knots.)
			Hours.	Distance.	Hours.	Distance.		
3	W.	⅓ Ebb	3	2·4 knots.	6	0·7 knot.	0·80	0·12
4	E.	½ Ebb	3	0·8 „	6	1·8 „	0·27	0·30
5 A	E.	Nearly H.W.	Nearly 6	0·75 „	6	1·7 „	0·12	0·33
B	E.	½ Ebb	3	0·5 „	6	1·5 „	0·17	0·25

That the wind had an undoubted action on the floats is seen not only from their respective paths, but also from the distances they travelled according as the wind was with or against the tide.

Thus in the first set (Series 3), the average speed of the floats on the ebb tide, when the wind was in the same direction as the current, was 0·8 knots per hour, but on the flood tide it was only 0·12. While in the other two series, when the wind was blowing in the opposite direction, the effect was reversed, the greater speed of the floats being on the flood tide and the lesser on the ebb. As an approximation, at all events, to the average speed of the tidal currents in the upper reaches of the Lough, we think that the mean rate of movement of the floats in all the different series may be taken. This it will be found amounts to 0·29 knots per hour on the ebb tide and 0·25 on the flood.

In any case the tides are clearly very sluggish, and there can be no doubt that the sewage poured into the Lough on a given ebb does not reach even the lighthouse. While, during the succeeding flood, it is driven back again towards the city, thus leading to the formation of a permanently polluted zone.

CARBONIC ANHYDRIDE PRESENT IN THE WATERS OF BELFAST LOUGH IN RELATION TO SEWAGE POLLUTION.

As elsewhere stated (see pp. 99–101) the method employed for determining the dissolved gases, consisted in boiling them out from the water samples *in vacuo* after the addition of sulphuric acid, and then submitting them to the usual methods of gas analysis.

The carbonic anhydride thus found (and given in the tables of results) is therefore the total amount and includes both the free and combined gas.

While the figures obtained by us in the case of the samples from Belfast Lough indicate that the total carbonic anhydride is to a considerable extent associated with salinity, decreasing as the latter increases, we are of the opinion that it is quite as dependent, if not more so on the extent of sewage pollution.

A complication is, however, introduced into our results by the fact that before determining the carbonic anhydride, the samples were often kept for three or four days, during which time the gas was no doubt produced in many cases. An approximate correction can, however, be made for this by deducting from the figures appearing in the tables of results, the volume of oxygen which disappeared on keeping the samples, as most of it is converted into carbonic anhydride which latter occupies the same volume as the oxygen it contains.

In the following table we give the amounts of carbonic anhydride obtained in the different series of analysis both with and without this correction arranged in the order of magnitude of pollution as indicated by the free ammonia.

	Series.	Number in Series.	Carbonic Anhydride c.c. per litre at N.T.P.		Nitrogen as :— Free Ammonia (parts per 100,000).	Chlorine (parts per 1,000).
			(without correction.)	(with correction.)		
1	5	4A	57·60	55·18	0·1320	18·52
2	4	3	53·09	?	0·0990	18·54
3	5	1	53·52	50·44	0·0860	18·40
4	5	4	50·85	48·75	0·0690	18·88
5	4	10	51·74	50·21	0·0580	18·62
6	1	6	54·11	53·64	0·0560	17·70
7	6	5	50·66	48·75	0·0527	18·80
8	3	1	50·87	?	0·0330	18·56
9	6	1	47·71	47·42	0·0296	18·80
10	2	2A	51·28	51·28	0·0263	16·02
11	6	3	47·55	46·99	0·0198	18·90
12	2	3	48·38	48·38	0·0148	18·82
13	2	1	47·67	47·67	0·0090	19·20
14	2	2	47·88	47·88	0·0085	19·20
15	1	3	47·69	47·69	0·0080	19·24
16	1	1	47·03	46·99	0·0050	19·22
17	4	8	45·64	45·12	0·0046	19·22
18	3	3	46·17	?	0·0041	18·96
19	3	6	46·06	?	0·0041	19·16
20	5	2A	45·73	44·93	0·0040	19·00
21	4	7	43·36	43·36	0·0033	19·20
22	6	7	44·70	44·49	0·0016	19·40

It will be seen that the sample containing the least carbonic anhydride (No. 21) was nearly the saltest, and also nearly the least polluted. But the sample containing the most carbonic anhydride (No. 1), though by no means the least saline, was the most highly polluted.

The least saline sample (No. 10) contained a considerable quantity of carbonic anhydride, but in its case also the pollution was quite decided.

Moreover several of the samples having almost identical salinity figures contained very different amounts of carbonic anhydride, *e.g.* Nos. 1 and 8, also Nos. 13 and 21. In these, and in several of the other examples given, it will be found that the higher proportion of carbonic anhydride is associated with the greater pollution.

It may not be safe to draw any very exact inferences as to the amount of carbonic anhydride alone as an index of sewage pollution ; but it would appear from the figures in the table that when the quantity reaches 48 c.c. per litre (at N.T.P.) or thereabouts, pollution is probably indicated, and that when it amounts to 50 c.c. the indication is decided.

APPENDIX.

By T. Carnwath, Esq., M.B.

BACTERIOLOGICAL METHODS.

Collection of Samples.—(1) Of water: These were taken from the large bottle in which the samples for the chemical examination were collected, the samples for both purposes being drawn from the common stock and syphoned off into smaller vessels, which for the bacteriological examination consisted of sterile glass-stoppered bottles of about 200 cc. capacity.

They were examined as soon after collection as possible. Never more than 12 hours were allowed to elapse between the time of collection and the time of examination.

(2) Of mud or silt: These were taken from the same dredgings as the samples used for chemical analysis.

Dilutions were made in the ordinary way with sterile tap water.*

Total Number of Bacteria.—Quantitative estimations were made of the total number of bacteria capable of developing in nutrient gelatine at 22° C. (2½ to 3 days), and also of those bacteria capable of developing in nutrient agar at 37° C. (36 hours). The proportion of the latter to the former is always very high (1 : 2 or 3) in crude sewage † whereas in pure water it is relatively low (1 : 20–50).

In order to make the figures as comparable as possible the same dilution was used for both the agar and the gelatine counts right through each given series. The method has one obvious disadvantage, in that, in some cases, the number of colonies on one plate may be so great that only an approximately accurate estimate can be formed. On the other hand, however, it obviates to some extent what we may call the "accidents" of dilution, and in a series of examinations like the above, where comparative numbers are of more value than absolute, it enables one to form, on the whole, I think, a more just conception of the relation of one sample to another.

"*Gas-formers*" *Bacillus coli, Streptococci.*—For the quantitative estimation of these organisms the American method, as practised by Prescott and Baker,‡ was adopted.

Fermentation tubes containing 2 per cent. glucose broth were inoculated with definite quantities of the sample to be examined and incubated for 16 to 20 hours at 37° C. At the end of this time the number of tubes showing gas-formation (= number of "gas-formers") was noted. Where the gas-production was very slight—merely a bubble or two—or did not become evident until the second day after inoculation a note of interrogation is placed.

To isolate the "gas-former" which almost invariably, especially in the case of the water samples, proved to be a member of the *Bacillus coli* group—a loopful of the broth was diluted and subcultured on the surface of gelatine plates, from which, after a suitable period of incubation at 22° C., Coli-like colonies were selected and further tested. The fermentation tubes were now replaced in the incubator. At the end of a second period of 16 to 20 hours the broth was again examined—this time for streptococci—in hanging drop. In many cases the organisms were isolated by means of litmus-lactose-agar. Where a streptococcus was actually isolated a positive mark is placed. A simple note of interrogation indicates that streptococci (?) were seen in the hanging drop, but that either no attempt was made to isolate them or that the attempt failed.

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* See Report on Some of the Chief Methods used in the Bacteriological Examination of Sewage and Effluents by Dr. A. C. Houston, presented with the Second Report of the Royal Commission on Sewage Disposal, 1902, Cd. 1178. [Page 137.]

† Houston, "Bacterial Treatment of Crude Sewage," 3rd Report to London County Council.

‡ Journal of Infectious Diseases I., p. 193.

The following tests were employed for the identification of *bacillus coli*—

1. Morphology, motile and Gram negative.
2. Characteristic growth on gelatine with absence of liquefaction.
3. Gas production in glucose broth (24 hours at 37° C.).
4. Clot and acid-formation in milk cultures (5 days at 37° C.).
5. Production of indol in peptone water (5 days at 37° C.).

As a control to the glucose broth method of isolating *bacillus coli*, phenol (·05 per cent.) peptone water cultures were also made. Experience proved, however, that this precaution was only necessary when examining mud samples. And even here it may be possible to dispense with it by incubating the glucose broth at a comparatively high temperature, as it has been shown that practically all strains of *B. coli* are capable of fermenting glucose even at a temperature of 46° C.*

Bacillus enteritidis sporogenes (*Klein*).—Whole milk tubes were used for this test. They were heated to boiling point immediately before use, then cooled, inoculated, heated again to 80° C. and kept at that temperature for ten minutes. They were then incubated for 36 hours at 37° C. without† taking any special anaerobic precautions.

RELATIVE VALUE OF THE DIFFERENT TESTS EMPLOYED.

1. *Total Number of Bacteria.*

a. On Gelatine (22°C). An unusual increase in the total number of bacteria in a water, may occasionally be due to other causes than contamination bysewage. The test cannot, therefore be considered a specific one. Where, however, the cause is obvious the " total number of bacteria " will give a valuable indication of the *degree* of the pollution. This is borne out by an examination of the foregoing tables where there is, as a rule, a rough correspondence between the gelatine count and the results furnished by the chemical analyses and by the *B. coli* test.

b. On Agar (37°C.). The same remarks may be applied to the agar count, with the addition that this test is somewhat more specific. A marked increase in the number of blood-heat organisms is always suggestive of pollution of animal origin.

Variations in the proportion of the agar to the gelatine count were determined, but the results were too discordant to be of value or to allow of any definite conclusions being drawn.

2. *Gas-forming Microbes.*—The number of these corresponds, in the main, with the number of *B. coli*. Occasionally a slight difference appears. (*cf*. Series I, No. 5.)

The test is a simple and valuable one and gives results which compare very favourably with those obtained by the employment of Dr. Houston's test.‡ The latter has theoretically the merit of including those bacteria which refuse to grow (and therefore, to form gas at blood heat, but in sewage and sewage polluted waters, the number of such gas-forming bacteria must be comparatively small.

3. *B. coli.*—This is, par excellence, the most reliable and the most specific test of sewage contamination. A scrutiny of the foregoing tables will show the remarkable consistency with which the *B. coli* results accord with the chemical. In only a very few cases is there any marked discrepancy between the two methods of examination.

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* C. Eÿkman—" Die Gärungs probe bei 46° C. als Hülfsmittel bei der Trinkwasser Untersuchung." Centrb. f. Bakt. 1, Abt. Bd. 37, p. 742.

† McWeeney, Report to Local Government Board for Ireland 1904 ; also Boyce, Grünbaum McConkey and Hill. This Com. Rep. No. 2, p. 102.

‡ See Report on Some of the Chief Methods used in the Bacteriological Examination of Sewage and Effluents by Dr. A. C. Houston, presented with the Second Repot of the Royal Commission on Sewage Disposal, 1902, Cd. 1178. [Page 146.]

4. *Bacillus enteritidis sporogenes.*—When it is taken into consideration that the Belfast sewage which contains, on an average, about 100 spores of *B. enteritidis sporogenes* per cc., undergoes in the lough a dilution varying from 1 : 10 in the neighbourhood of the "shoot" to about 1 : 1,000,000 in the neighbourhood of the lighthouse, it will be evident why so few positive results were obtained with the dilutions employed. The only exception is Series II. where the results are probably to be explained by the fact that on the day on which the samples were collected it was very stormy and the water was as a consequence, more turbid than usual.

The test, *as* a test, is easy to apply, and is particularly useful in the examination of dredgings.

5. *Streptococci.*—The precise value of this test is still *sub judice.* That the *streptococcus*, however, cannot well be regarded as a very delicate organism and, therefore, as an index of *recent* sewage contamination,* may be inferred from the fact that in mixtures of sewage and seawater (1 : 100) it survives for a very long time. I have actually isolated from such a mixture a typical *streptococcus longus* at the end of 127 days—long after *B. coli* could be detected.

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* Houston, "Bacterial Treatment of Crude Sewage," 3rd Report to London County Council.

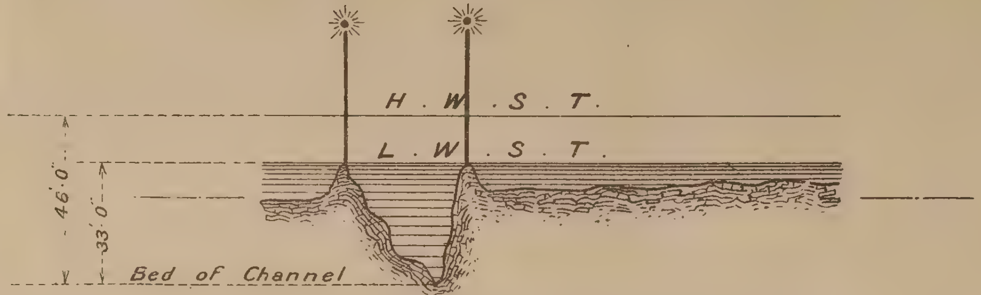
SECTION 7B.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

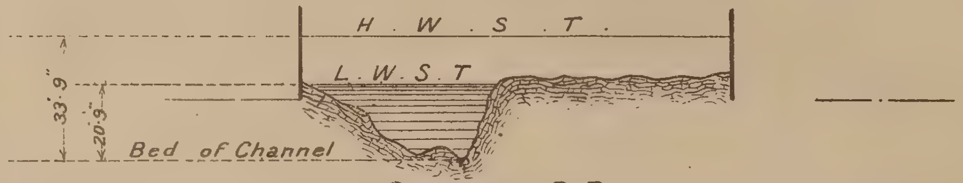
THE ESTUARY OF THE RIVER LIFFEY (DUBLIN).

ROYAL COMMISSION ON SEWAGE DISPOSAL

Fig: 1.



SECTION A.A.



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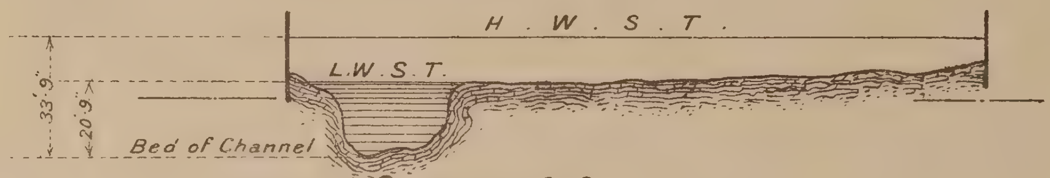
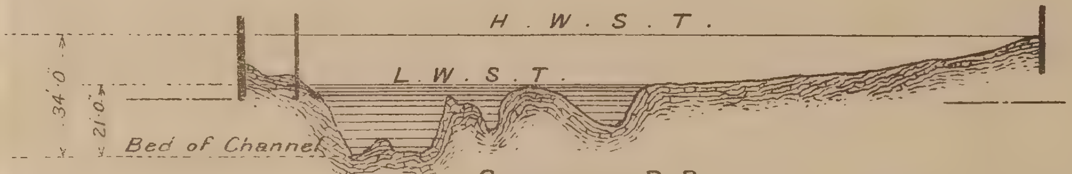


SECTION C.C.



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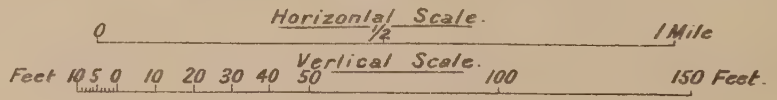

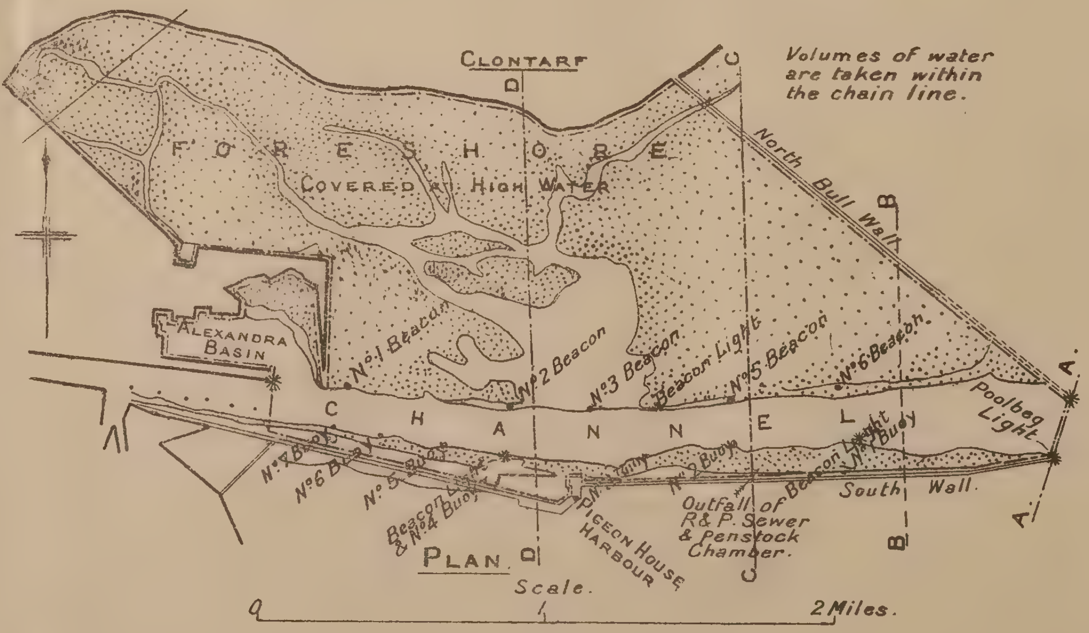

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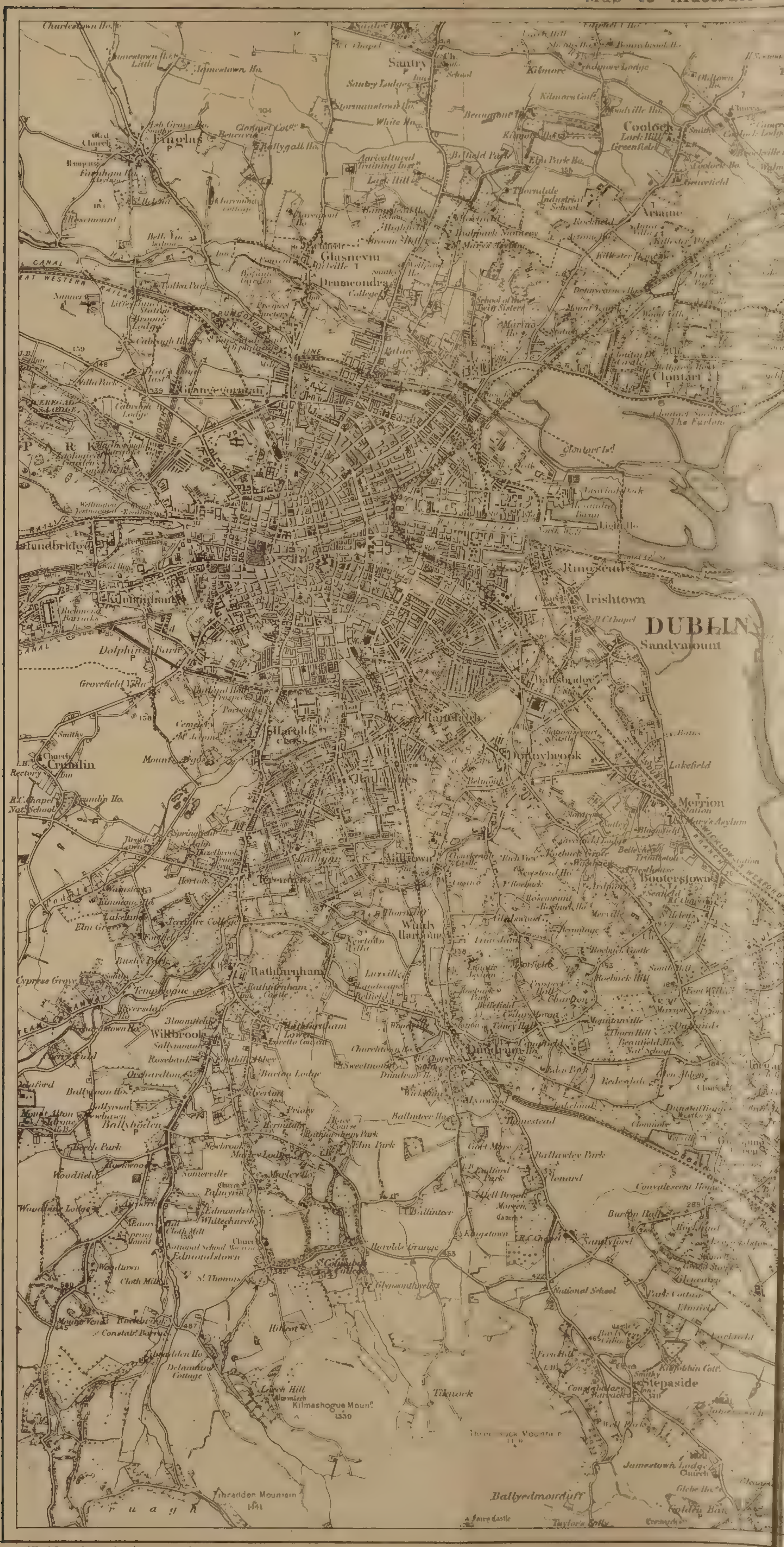
Map to illustrate D



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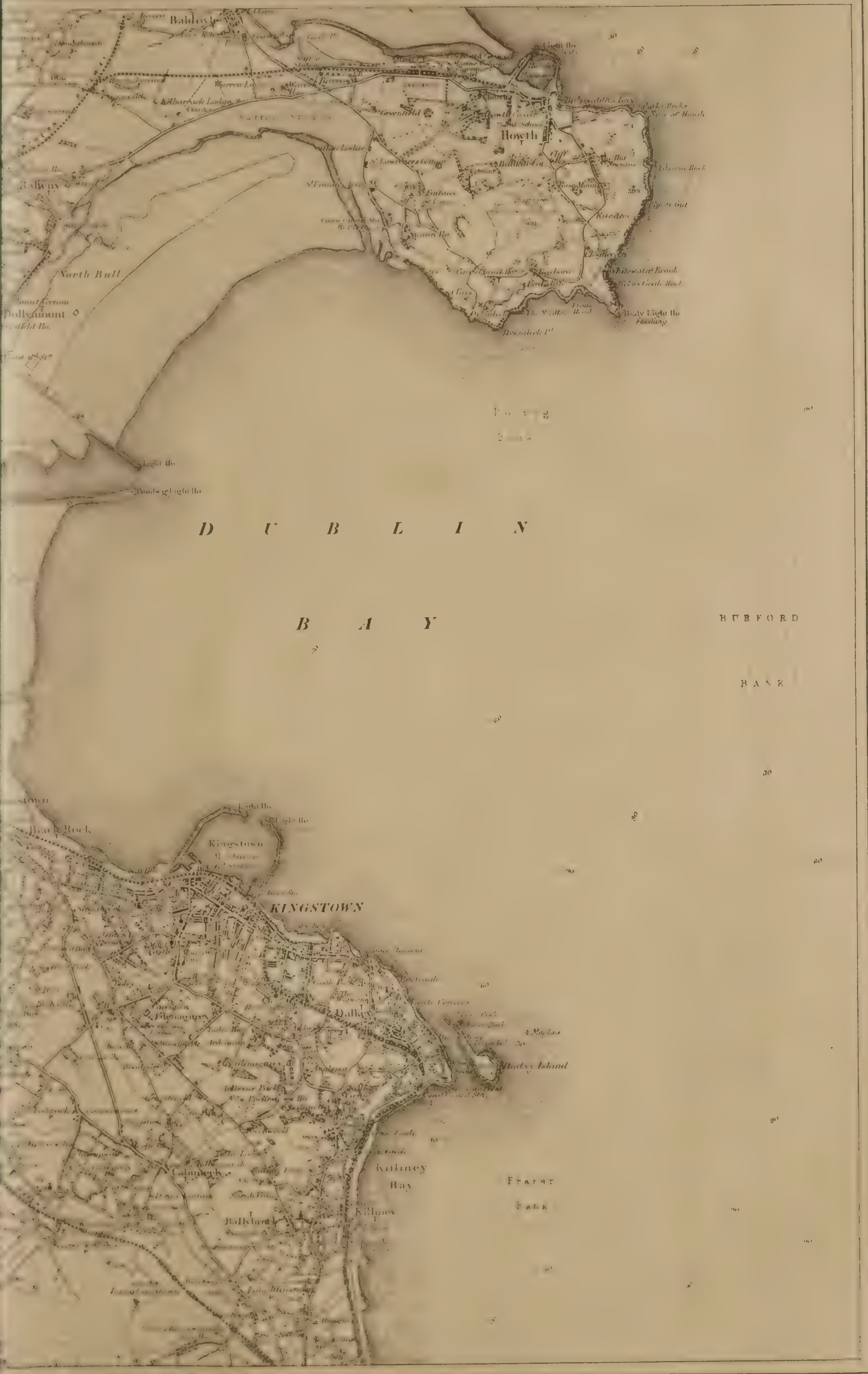
A.

ION ON SEWAGE DISPOSAL.

deney's Section on the Liffey Estuary.

PART OF SHEET 112.



Inch to One Statute Mile — 63360

4 Miles

Printed at the Ordnance Survey Office, Southampton in 1907

THE ESTUARY OF THE RIVER LIFFEY.

TOPOGRAPHY.

Dublin is situated on the Liffey at the head of a bay 6 miles deep and 5½ miles wide. Large quantities of sand, brought in by the sea, have accumulated in the bay, forming extensive strands, which are laid dry at low water for a distance of about 2½ miles seaward. The position of Dublin and of these strands will be understood from the accompanying map, which is reproduced from the Ordnance Map of Ireland.

A plan of the estuary of the Liffey and a series of sections, taken through the deep water channel, are shown by Fig. 1. It was originally prepared by W. Kaye-Parry, M.A., M.Inst.C.E., and it is here reproduced, by the kind permission of the Council of the Institution of Civil Engineers, from a communication by him and by one of the authors (Adeney), entitled, " The Discharge of Sewage into a Tidal Estuary," and published n the proceedings of that body, Vol. 147, Part 1, 1902.

It will be seen from the plan that the estuary waters are confined by two walls, the South Wall, on the south side, and the North Wall, on the north-east. The latter is about 9,400 feet in length; of this, about 6,000 feet, from its commencement at the Dollymount shore, is constructed to a height of 6 or 7 feet above high water, the remaining 3,400 feet being carried up to half tide level only. To quote from a paper communicated by Mr. John Purser Griffith to the Institution of Civil Engineers on " The Improvement of the Bar of Dublin Harbour by Artificial Scour,"* it is necessary to have a general knowledge of the currents in the bay, fully to appreciate the value of the Great North Wall; " and for this purpose the most important fact to be borne in mind is, that on the north side of the bay, during the first half of the ebb, the tide runs westwards towards the bar, and then southwards in the direction of Kingstown, while during the last half of the ebb and the whole of the flood, the tide sets eastwards past the Bailey. During the first half of the ebb, the tidal and river waters within the Great North and South Walls pass partly over the submerged portion of the northern embankment, and partly through the harbour entrance between its termination and Poolbeg Lighthouse. The current out of the harbour during this time is comparatively slack, and in no way interferes with the navigation of vessels in and out of the port. It is also probable that it produces little or no effect in deepening the bar channel, but only joins the bay currents, and sets south towards Kingstown. As soon, however, as the lower portions of the northern wall is uncovered, the remainder of the tidal and river waters within the harbour must pass through the contractive entrance at Poolbeg, which is only 1,000 feet wide. The result is a great increase in the velocity of the current, which somewhat exceeds three miles per hour during spring tides, and a marked impression on the bar by the removal of sand. This sand-bearing stream joins the bay current, which by this time is setting eastwards, and ultimately deposits on the North Bull a portion of the sand from the bar, while the rest is carried into deep water.

" The tidal water entering on the flood comes from the south, bringing back some of that discharge on the first half of the previous ebb. It appears, however, that except at neap tides, but little of the water discharged during the second half of the ebb returns, in consequence of the current of the north side of the bay still setting east, and that the harbour is thus safe from injury by the return of sand upon the flood tide."

A deep water channel extends from the river through the estuary in a practically straight line to the entrance at Poolbeg, a distance of 5½ miles, measured from the Custom House. The tidal portion of the river continues from this point to the weir at Islandbridge, a distance of 1½ miles.

The South Wall runs parallel and quite close to the deep water channel, leaving but a narrow strip of foreshore, the lower portion of which, below the old Pigeon House

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* Trans. Vol. 58, Part IV., 1878–79.

Harbour, which is shown on the plan, is not more than 200 yards wide, and is only exposed at low spring tides.

On the north side of the deep water channel, a very considerable area of foreshore or slob land exists, which is uncovered at low water. It is over a mile in width and nearly three in length.

The tidal portion of the river is confined within quay walls, and, as already indicated, forms a deep water channel, from 100 to 200 feet wide, as far as the Custom House, close to which the river is spanned by the O'Connell Bridge.

The River Dodder joins the Liffey on its right bank, immediately above the estuary. It is marked on the plan. A small river, the Tolka, flows directly on to the north-west corner of the estuary at Fairview.

The estuary within the walls, and to some distance eastwards beyond the Poolbeg and Bull Lighthouses, together with the tidal portions of the river, form the Dublin Harbour.

HISTORICAL NOTES.*

In the year 1707, the combined waters of the Liffey and Dodder flowed across the sands at low water, dividing them into the North Bull and South Bull. From its exposed position, the channel thus formed was subject to constant alteration in depth and direction, and this being the only channel by which vessels could reach the city, the early attempts to improve the harbour took the direction of providing a permanent and deep water approach to the port. With this end in view, the great South Wall was constructed, during the eighteenth century, to shelter the channel from southerly winds, and also to prevent the encroachment of sand.

Improvement of Channel across the Bar.

Although the completion of the Great South Wall accomplished to a great extent the object aimed at by its designers, portions of the channel up to the city were still very shallow, and attention was also drawn to a shoal beyond the extremity of the new wall, known as Dublin Bar. This bank stretched from the north side of the bay across the entrance to the harbour in the form of a hook. The deepest water for vessels was round the end of this hook; and across the bank, in a direct line out to sea, there was a depth of only from 5 to 6 feet at low water of spring tides. At the beginning of the nineteenth century many eminent engineers and naval officers were consulted respecting the further improvements. Captain Bligh recommended a wall along the north side of the channel; Sir Thomas Hyde Page proposed a similar wall, and the formation of an island on the bar; while the proposal to construct an embankment, or wall extending from the north shore towards Poolbeg emanated from the Corporation for preserving and improving the Port of Dublin. Mr. Rennie, at that time considered the highest authority on the improvement of harbours, prepared an elaborate scheme, but he predicted little likelihood of much improvement on the bar. He expected an increased depth of 3 feet of water as a result of an estimated expenditure exceeding £655,000. To provide a better approach, he considered it essential to construct a ship canal from some point on the adjacent coast where deep water might be obtained, and finally recommended the entrance to be made close to the present site of Kingstown Harbour. His estimate for this work was £489,734. From 1802 to 1812 the question of the improvement of the bar appears to have been in abeyance. Probably from Mr. Rennie's scheme, from the large expenditure it would have involved, and the smallness of the results anticipated, tended to deter the Government from advancing the necessary funds for any particular scheme.

About 1819 the Ballast Board found themselves in a position to carry out their own project of a wall or embankment from the Clontarf shore. Its object was to protect the harbour on the north side from the encroachment of sand, to shelter it from

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[*] These notes have been taken from an interesting paper, which was read by Mr. John Purser Griffith, M.Inst.C.E., Engineer of the Dublin Port and Docks Board, at the summer meeting of the Forty-fourth Session of the Institution of Naval Architects, June 26th, 1903.

northerly and easterly winds, and to direct the tidal and river waters in a fixed channel across the bar. Before beginning this work, however, an accurate survey of the river and bar was made by Mr. Francis Giles. Under the joint direction of Mr. Giles and Mr. Halpin, the engineer of the Ballast Board, the rubble embankment, now known as the Great North Wall, was constructed.

A consideration of the difficulties overcome in the improvement of the approach to the Port of Dublin naturally leads to the inquiry, What are the dangers which beset the maintenance of the deep water channel across the bar? These may be briefly summarized as reclamation within and outside the harbour. Reclamation inside would reduce the tidal capacity on which the scour across the bar depends; while reclamation outside would result in the reduction of the area upon which sand entering the bay is at present deposited, and would tend to drive the low-water mark further out to sea, and greatly endanger the channel across the bar.

It may be contended that the channel across the bar can be maintained by suction dredging, without imposing any restrictions on reclamation. This is, of course, true; but, although suction dredging is relied upon for the improvement of the channel across the bar, yet the tidal waters of the harbour must form an important factor in its economic maintenance. The objections to reclamation are, therefore, as great as ever.

Dredging River Channel.

The great works which proved so efficacious in increasing the depth of the water on Dublin bar produced no appreciable improvement in the river channel. From the city to within 1,000 feet of Poolbeg Lighthouse all improvements in the channel are the result of dredging. Steam dredging was first introduced in 1814, but up to 1860 the total average tonnage raised did not exceed 150,000 tons a year.

Since 1860 nearly 24,000,000 tons of materials have been dredged between Butt Bridge and Poolbeg, and the channel has been thus deepened, straightened, and widened for a length of 4 miles. A sum of £529,000 has been expended upon this work, exclusive of cost plant, which represents a further expenditure of over £150,000. Up to the year 1900 dredging operations were exclusively confined to the harbour to the westward of Poolbeg, all improvement of the bar being due to the tidal scour already referred to. Captain Pirie's survey of 1899 (undertaken at the instance of the Port Board) brought to light, however, an encroachment of the North Bull strand upon the channel across the bar. To check this encroachment the Board decided to employ suction dredging, and an experimental contract was entered into for the removal of 750,000 tons of sand from the bar and the pumping of the sand ashore upon the slob lands at the north side of the Alexandra Basin. This has proved successful, and the Board have recently (1903) contracted for the building of a suction hopper dredger suitable for this work, in order to carry out the dredging departmentally. The programme in view at the time was to construct within the then next five years a channel from the bay to the city with 20 feet depth at low water of spring tides. This would open the port to all classes of vessels engaged in the coasting trade at all times of the tide, and permit the largest class of oversea merchant vessels to enter at neap tides. This may be said to be a modest programme, but it will be a great step in advance, and there is no reason why this depth should not be increased if found necessary.

New Quay Walls.

The old shipping quays were built in the early part of the nineteenth century, and were founded about low-water level, and the foreshore in front of the quays dried out at low-water mark. A length of about 7,500 feet (or about 50 per cent.) of these quays to the eastward of Butt Bridge have been rebuilt at a cost of about £360,000. This enables some of the principal coasting and cross channel steamers to sail at fixed hours irrespective of the time. A large portion of these reconstructed quays are on the south side of the river, and there are deep water berths available for over-sea as well as coasting vessels, and at the greater portion of these latter quays there is a depth of 22 feet alongside at low water.

North Quay Extension and Alexandra Basin.

New deep water quays and a large tidal basin called the Alexandra basin (fig. 1) have been constructed on the north side of the river. These new quays have already added 40 per cent. to the length of the river quays to the eastward of Butt Bridge. The quay walls of the North Quay Extension and Alexandra Basin have attracted much attention amongst engineers, owing to the manner in which they were constructed. They were built up to low-water level with gigantic blocks of masonry, each block weighing 350 tons, and over the blocks the upper portion of the walls was built by tidal work. The blocks were built on a wharf, and when sufficiently hardened were lifted and conveyed to their destination in the quay wall by a floating shears. The foundation for the blocks was first excavated by a steam dredger to within two feet of the finished level, and the remainder of the excavation was taken out by men working in a large diving-bell, 20 feet square and 6½ feet high. Access was obtained to this chamber by a wrought-iron shaft and air-lock without lifting the bell. One of the most important features of this mode of construction is the absence coffer-dams, staging, and pumping; and it has proved exceptionally economical. The whole of the machinery and appliances in this great work were designed by Dr. Bindon Stoney, LL.D., F.R.S., M.Inst.C.E., the late chief engineer of the Dublin Port and Docks Board. The quays on the river side of the North Quay Extension afford berthage of 22 feet at low water, while the berths along the quays inside the Alexandra Basin have depths of 24 to 26 feet at low water. The Alexandra Basin is still unfinished.

Lights, Fog-Signals, Beacons and Buoys.

There are five lighthouses. Poolbeg Lighthouse is the oldest in the Port, having been built in the middle of the eighteenth century. The fog signal at this lighthouse is a powerful siren sounded by compressed air. The base of Poolbeg Lighthouse is protected on the east and south-east by a breakwater of concrete blocks, each weighing 140 tons.

The North Bull Lighthouse is a wrought iron tower on a masonry base, founded on the submerged end of the Great North Wall. The lower portion of the masonry consists of two concrete blocks each weighing 330 tons.

In addition to the lighthouse the channel is also marked by beacons on the north side, and by buoys on the south side, two of the latter being illuminated buoys.

CONTENTS OF DUBLIN HARBOUR.

A careful computation has been made by Kaye-Parry of the quantity of water contained in Dublin Harbour between the Alexandra Basin (shown on the plan, figure 1) and Poolbeg Light, at different states of the tide, with the following results :—

At high water of spring tides - - - - - - -	9,228,000,000 gallons.
At low water of spring tides - - - - - -	2,374,500,000 ,,
At high water of neap tides - - - - - - -	7,414,500,000 ,,
At low water of neap tides - - - - - - -	3,183,000,000 ,,

These figures show that during the spring tides 6,835,500,000 gallons of tidal water pass in and out of the harbour at each flow and ebb, and similarly 4,231,500,000 at neap tides. In addition to these volumes of tidal water, there is that of the river water, the daily average volume of which has been calculated to amount to 270,000,000 gallons.

Of the quantity of water which remains in Dublin Harbour at low water, 91 per cent. is contained in the deep water channel at spring tides, and 78 per cent. at neap tides.

As already stated, owing to the nature and direction of the tidal currents, very little of the water which passes out of Dublin Harbour on the second half of an ebb tide returns with the ensuing flood tide, except perhaps at neaps.

POLLUTION OF THE RIVER AND ESTUARY.

For very many years past the Dublin Harbour has been the receptacle of the sewage in a crude state from the City of Dublin, and from the adjoining townships and country districts. The total population included in these areas amount to upwards of 360,000.

The sewage from the greater part of the City of Dublin is discharged into the tidal portion of the River Liffey by a number of sewers opening out along the quay walls on either side of the river. The remainder of the city sewage is discharged into the river Tolka at Ballybough Bridge, which is close to the mouth of the river, and is thence brought down to the foreshore of the estuary at Fairview.

The sewage from Clontarf is discharged by means of a number of open sewer pipes on to the foreshore to the north of the deep water channel, The positions of the sewers may be gathered from the maps which will be described a little later on, see page 278; it may be taken that a sewer runs on to the foreshore in a straight line from every side street shown on the maps.

The townships of Rathmines and Pembroke, which together possess a population of upwards of 60,000 people, have a joint main drainage system, independent of that of the City of Dublin, and the sewage is discharged from an outfall which is situated close to the south wall, about a mile above the mouth of the harbour. Its position is indicated on the plan in figure 1. The discharge from this outfall is legally limited to the first five hours of the ebb tide.

The invert of the outfall sewer is covered by 5 feet of water at low water of equinoctial springs, and during the period of discharge the depth of water over it varies between 8 and 18 feet.

THE CONDITION OF THE BED OF THE RIVER AND ESTUARY.

From the point of view of sewage disposal, the estuary presents an exceedingly interesting object lesson. Notwithstanding the large volumes of crude sewage which are discharged into both river and estuary, gross pollution of the bed is by no means general, but is restricted to comparatively small areas. For example, it may be stated on the authority of the engineer to the Dublin Port and Docks Board, Mr. John P. Griffith, M.Inst.C.E., that practically the whole of the sewage solid matters which are discharged into the river are deposited within the river area. This statement is based on the observation that in dredging operations sewage solids are not met with below the neighbourhood of the Alexandra Basin, shown on the plan. Below this point the bed of the channel is quite free from anything like serious pollution. Finely divided sewage solids are no doubt carried below this point, and become widely distributed, since the bed of the estuary has been observed very generally to be polluted, although very slightly so.

Again the bed of the estuary in the neighbourhood of, and below the joint outfall works of the Rathmines and Pembroke townships is remarkably free from any permanent deposit of sewage solids, although the outfall has been in operation for over twenty-five years. The solid matters which are met with in the neighbourhood of this outfall are confined to paper and to the light flocculent matters peculiar to domestic sewage, and to the floating matters common to town sewage, such as corks vegetable débris of various kinds, fine cinders, etc. Deposits of mud have been met with during dredging operations along the edge of the deep water channel below this outfall which did not occur before it was constructed. The mud appears to consist of fine road débris, and gives trouble in working suction dredgers. It does not appear to be seriously polluted by sewage solids.

The explanation of the absence of sludge banks in the neighbourhood of and below the outfall lies in the fact that the heavy road detritus is separated from the sewage before discharge of the latter from the outfall by a system of catch-pits built within the main sewers, and in consequence only the floating matters and lighter solids escape with the liquid matters from the outfall. These are too light or too finely divided to form *permanent* deposits anywhere, and are either carried out to open sea, or too widely distributed to cause any nuisance or observable pollution.

The condition of the foreshore north of the deep water channel is also extremely instructive. At the mouth of the Tolka, in the neighbourhood of Annesly Bridge, it is grossly polluted by sewage solid matters, but the pollution gradually lessens in the direction of Dollymount where the surface of the sand is quite clean, and it is necessary to dig down some four or five inches to obtain any sign of the discolouration due to pollution.

Along the less polluted portions of this foreshore masses of the green *ulva latissima* accumulate during the summer and autumn and gives rise to extremely offensive odours.

One of the authors (Letts) has made careful analysis of samples of sand and gravel which he dredged from different parts of the river and estuary. The results very clearly show the degrees of pollution which obtain at different points of the bed of both river and estuary.

A small dredge with bag of canvas material was employed so as to lift both coarse and fine particles. The dredging was done on the flood tide. The samples of sand etc., thus obtained were dealt with as follows :—

(1) A certain quantity of each was placed in a small specimen tube which was corked. The object of this was to ascertain whether or no putrefactive changes would occur. Sand or silt polluted with sewage blackens when kept in a moist condition, while the same if not polluted does not materially change in appearance.

(2) The bulk of the material dredged in each case was dried, then sifted through fine wire gauze and the finer portions analysed. The siftings were submitted to two different methods of chemical examination, viz. :—

(*a*) The loss in weight when they were heated or "ignited";

(*b*) An analysis to determine the amount of nitrogen which they contained.

Both methods give an indication of sewage pollution, but the second is the more sensitive, and the results obtained by it were employed in calculating the probable percentage amount of sewage sludge in different examples.

For this purpose it was necessary to examine the sludge itself, and samples of this material were on three occasions dredged from the bottom of the valve chamber of the Rathmines and Pembroke outfall works, and were submitted to the same methods of analysis.

The average amount of nitrogen in them was found to be 2·7 per cent., and this figure has been taken as the basis of calculation and as representing 100 parts of sewage sludge.

The figures in the column headed "probable percentage of sewage sludge without correction," in the following table, 1, have been arrived at from the proportion 2·7 : 100 : : percentage nitrogen in the dredging : probable percentage sewage sludge.

But unpolluted sand contains a certain amount of nitrogen (no doubt due to animal and vegetable débris) and a correction should be made for this. For this purpose the percentage of nitrogen found in the sand on the white strand to the south side of the wall at the outfall works. In the column headed "probable percentage of sewage sludge with correction," the percentage of nitrogen in the unpolluted sand has been subtracted from that found in the polluted samples, and the remainder taken as the true index to the extent of the pollution. The position on the bed of the estuary where the samples were dredged will be found marked on the map which accompanies Table 1.

TABLE I.—ANALYSES OF DREDGINGS AND OF SEWAGE SLUDGE, 1905 (*Letts*).

No.	Nature of Sample.	Percentage of Nitrogen.	Percentage Loss on Ignition.	Probable Percentage of Sewage Sludge.		Remarks.
				Uncorrected.	Corrected.	
1	Liffey R. at mouth of Dodder.	0·934	24·9	34·6	34·1	Black, flocculent, stinking contained an extraordinary number of small worms. On keeping in a moist condition turned very black. On ignition heavy white ammoniacal vapours were evolved and complete charring occurred.
2	Harbour—abreast of Pigeon House.	0·204	2·4	0·8	0·3	Fine grey sand. On keeping in a moist condition blackened in patches; on igniting did not char or emit any perceptible odour or vapours.
3	Harbour—midway between Pigeon House and Outfall.	0·108	4·6	4·0	3 5	Coarse pebbles and shells in addition to sand. On keeping in a moist condition blackened in patches but more extensively than 2. On igniting blackened slightly and emitted a slight odour, without however visible vapours.
4	Harbour—50–100 yards below Outfall.	0·059	4·4	2·2	1·7	Many coarse pebbles, shells and a shell-fish or two in addition to sand. On keeping in a moist condition turned black; on igniting blackened distinctly and emitted a distinct odour without however visible vapours.
5	Harbour—Just inside Light Buoy.	0·038	2·0	1·4	0·9	Many course pebbles and shells in addition to sand. On keeping in a moist condition blackened somewhat; on igniting blackened distinctly and emitted a slight odour without however visible vapours.
6	Harbour between N. Bull and Poolbeg Lighthouse.	0·006	2·5	0·6	0·1	Some pebbles and a good deal of fine gravel and shells in addition to sand. On keeping in a moist condition did not change; on igniting did not blacken or emit smells or vapours.
7	Harbour—North side of Channel at Red Buoy.	0·019	3·4	0·7	0·2	Fine sand. Behaved like 6 on igniting.
8	Harbour—North side of Channel, off lowest beacon.	0·019	2·0	0·7	0·2	Similar to 7 in all respects.
9	South side of Wall, "White Strand" at Valve House.	0·013	1·5	0·5	0·0	Coarser than 6 and 7 but similar to them in all respects.
10	Sewage sludge (Flood sample).	1·615	40·5	—	—	
11	Sewage sludge (Dry sample).	3·887	30·2	—	—	
12	Sewage sludge (Dry sample).	2·562	31·0	—	—	

In reviewing the figures in the foregoing table, it is evident that the bed of the River Liffey at the mouth of the Dodder is enormously polluted. It in fact requires no chemical analysis to prove this; the filthy appearance and stench of the black mud dredged up being sufficiently convincing.

The next set of figures indicate that the bed of the estuary abreast of the Pigeon House is practically clean and unpolluted, while the succeeding set show that lower down it is distinctly polluted. This appears contradictory, but the probable explanation is that, as dredging operations were in progress at the time the samples were collected, the first of these two samples was taken from a spot already cleaned by the dredger, while the second was probably taken from a place where the dredger had not been recently at work, and which therefore contained an older and more polluted deposit. The results which will be found in the next table show that this explanation is in all probability the correct one.

The fourth set of figures in the above table were obtained from a sample collected 50 to 100 yards below the Rathmines and Pembroke outfall, and they show surprisingly little pollution. There can be no doubt that a large amount of sewage solids pass out over this spot, and also that a considerable quantity of these must occasionally be deposited where the sample was collected (the position is marked on the accompanying map of Dublin Harbour), but it seems clear from the analysis that they do not remain permanently deposited to any large extent, and that the small quantities which may from time to time be deposited are comparatively rapidly fermented in the presence of the dissolved oxygen in the water flowing over them, with the result that the bed is kept relatively clean, even quite close to the outfall.

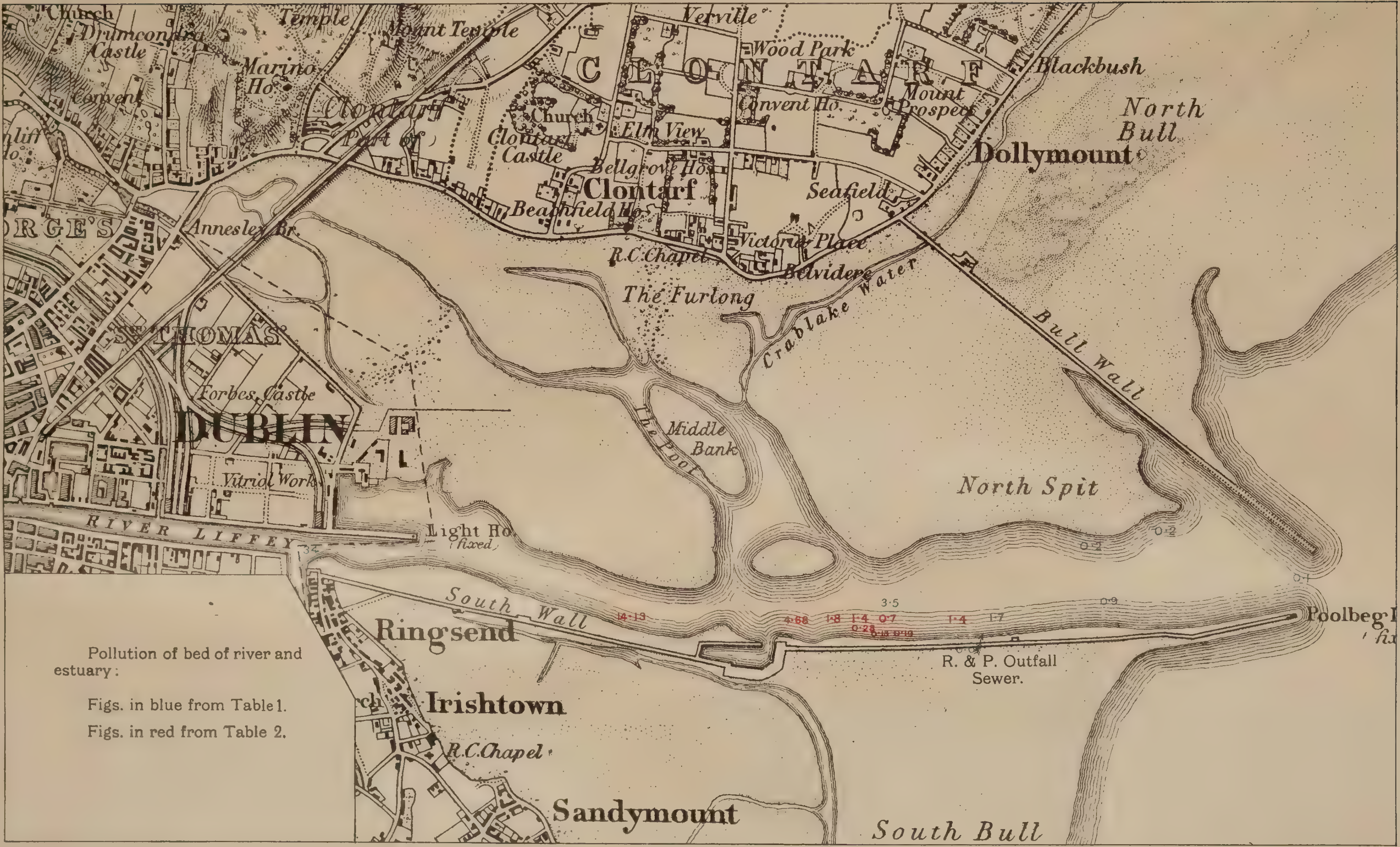
TABLE 2.—ANALYSES OF DREDGINGS AND SANDS EXPOSED AT LOW WATER, 1905 (*Letts*).

No.	Nature of Sample.	Percentage of Nitrogen.	Percentage Loss on Ignition.	Probable Percentage of Sewage Sludge.		Remarks.
				Uncorrected.	Corrected.	
1	50 yards above Rathmines sewer overflow above Pigeon House.	0·395	14·53	14·63	14·13	Fine mud. Slightly foul. On keeping turned black (*i.e.*, when kept moist). On ignition heavy white ammoniacal vapours evolved, and complete charring occured.
2	About 180 yards below Pigeon House.	0·140	7·70	5·18	4·68	Mud and sand. Not foul. On keeping blackened. On ignition charred and emitted slight smell, without, however, visible vapours.
3	About 360 yards below Pigeon House.	0·062	4·31	2·29	1·79	Fine sand. Did not blacken much on keeping. On ignition charred only slightly. Slight smell noticed, but no visible vapours.
4	About 540 yards below Pigeon House.	0·052	3·34	1·92	1·42	Fine sand. Not foul. On keeping blackened only slightly. On ignition charred slightly, but scarcely any smell emitted and no vapours.
5	About 720 yards below Pigeon House.	0·033	3·28	1·22	0·72	Some coarse fragments, such as coal, pebbles and shells. The remainder fairly fine sand. On keeping blackened in patches. On ignition charred slightly, but scarcely any smell emitted, and no vapours.
6	900 yards below Pigeon House.	—	—	—	—	Coarse stones and shells. Dredgings twice done, but no fine matter suitable for analysis obtained.

B.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Map to illustrate Dr. Adeney's Section on the Liffey Estuary.



Ordnance Survey, Southampton.

TABLE II.—Analyses of Dredgings and Sands Exposed at Low Water, 1905 (*Letts*)—*continued.*

No.	Nature of Sample.	Percentage of Nitrogen.	Percentage loss on Ignition.	Probable Percentage of Sewage Sludge.		Remarks.
				Uncorrected.	Corrected.	
7	About 1,080 yds. below Pigeon House, *i.e.*, nearly abreast outfall.	0·052	3·87	1·92	1·42	Fair amount of coarse material, e.g., pebbles and shells. On keeping blackened in patches. On ignition charred slightly, but scarcely any smell emitted, and no vapours.
8	Sand taken from east end of bank exposed at low water between Pigeon House and outfall.	0·019	2·37	0·69	0·19	Coarse sand, with some small shells and pebbles. On keeping scarcely blackened. On ignition blackened very slightly, but emitted no vapours.
9	Ditto middle bank.	0·017	1·93	0·63	0·13	Similar to 8. On keeping blackened slightly. On ignition behaved like 8.
10	Ditto west end -	0·021	1·78	0·78	0·28	Similar to 8. On keeping blackened slightly. On ignition behaved like 8.

The other figures need but little comment. They show that the effects of the sewage discharged from the outfall rapidly diminish as its neighbourhood is left, and are practically nil between the Poolbeg and North Bull Lighthouses.

It has been suggested that a great portion of the Rathmines and Pembroke sewage does not escape into the open sea, but remains within the harbour and is driven over by the flood tide on to the Clontarf strand. The figures obtained for samples 7 and 8 show that so far as sewage solids are concerned, the effect of the sewage if it is so carried over is practically nil.

The results of analysis of another series of dredgings by the same author are recorded in the next table, 2. These show in the first place the effects of the Dublin sewage are clearly traceable some distance down the harbour, but that they practically die out before the outfall of the Rathmines and Pembroke sewer is reached (6). No. 7 taken just off the outfall shows how slight the polluting effect of this sewer is on the bed of the harbour, while both of these taken together indicate with sufficient clearness that no appreciable quantity of sewage solids is carried towards Dublin with the flood-tide from the Rathmines and Pembroke sewer.

Regarding the possible effect of the overflow of the Rathmines and Pembroke sewer, situated near the Pigeon House, the river bed is here so much polluted by Dublin sewage that no inferences are possible.

The analyses of the exposed sands show them to be clean and scarcely affected either by the Dublin sewage or by that from Rathmines and Pembroke.

CONDITION OF THE WATERS OF THE ESTUARY IN 1900.

A study of the waters of the estuary abreast and below the Pigeon House was made by one of the authors (Adeney) in the winter and spring of 1890, and the results obtained have been in great part published in the joint communication with Kaye-Parry already referred to. Much of the information which follows is quoted from it.

Later on, in the years 1904 and 1905, further studies of these waters were made by the same author.

The first study was undertaken more particularly to ascertain the effect of the sewage from Dublin and from the townships' outfall upon the estuary waters abreast and below the Pigeon House.

As the results which have been obtained show that the Liffey estuary is a typical example of the second class in the division of tidal waters adopted in the Section on Chemical Changes, p. 67, it has been thought desirable to describe them in detail in this Report, more especially as they form the most complete study of actual pollution of a tidal water by the aeration method that has yet been recorded.

Volumes of Sewage Discharged from the Rathmines and Pembroke Outfall.

The sewage from the townships is impounded in a tank sewer during the last hour of the ebb and during the ensuing flood-tide. A careful determination of the quantity discharged from the outfall during each of the five hours when the sluice gates are open, at both neap and spring tides, has been made.

Mr. Kaye-Parry has kindly given the authors for insertion in this Report a copy of the results of observations which he made in 1905. They are as follows :—

TABLE 3.—SHOWING THE RELATIVE VOLUMES OF SEWAGE DISCHARGED PER HOUR FROM THE RATHMINES AND PEMBROKE OUTFALL TANK SEWER ACCORDING TO THE HEIGHT OF THE WATER AT HIGH TIDE.

APRIL 11TH, 1905.—HIGH WATER AT DUBLIN BAR 2.56 P.M. (AVERAGE TIDE).

——	Volume discharged.*	——
	Gallons.	Percentage.
First hour - - - - -	1,422,919	46·0
Second hour - - - - -	632,350	20·4
Third hour - - - - -	504,881	16·3
Fourth hour - - - - -	281,412	9·0
Fifth hour - - - - -	253,625	8·3
Totals - -	3,095,187	100·0

APRIL 20TH, 1905.—HIGH WATER AT DUBLIN BAR 11.25 A.M. (SPRING TIDE).

——	Volume discharged.*	——
	Gallons.	Percentage.
First hour - - - - -	938,562	30·3
Second hour - - - - -	844,212	27·3
Third hour - - - - -	769,719	24·8
Fourth hour - - - - -	289,069	9·3
Fifth hour - - - . -	253,625	8·3
Totals - -	3,095,187	100·0

At spring tides high water at Dublin Bar is about 12 o'clock noon and 12 o'clock midnight. The range of spring tides is about 13 feet.

During spring tides the difference in level between the liquid impounded in the sewer and the water in the estuary, when the sluices are first opened, is only about 3 feet. For this reason the quantity discharged during the first hour of spring tides is less than the quantity discharged during the corresponding period at neap tides.

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* Note the storage capacity of the tank sewer is 1,700,000 gallons, so that the sewer was overflowing on both the days these observations were made, before the sluices were opened. It appears from these figures that the capacity of the storage tank is insufficient, so that the sewage must overflow the valves of the Penstock Chamber during the flood tide.

At neap tides high water at Dublin Bar is about 6 o'clock a.m. and p.m. The range of tide is about 6 feet 6 inches. At neap tides the difference in level between the liquid in the sewer and the water in the estuary, when the sluices are first opened, is about 6 feet, and for this reason the discharge during the first hour is greater than at spring tides.

It will be observed that, practically speaking, 83 per cent. of the total quantity of sewage is discharged during the first three hours at both spring and neap tides, and about 9 per cent. during the fourth hour and 8 per cent. during the fifth.

Composition of the Sewage discharged from the Outfall.

The composition of the sewage which is discharged from the main drainage outfall is as follows:—

	Gallons.
Sewage from Rathmines, population 35,000, water consumption 44 gallons per diem	1,540,000
Sewage from Pembroke township, population 25,000, water consumption 40 gallons per head per diem	1,000,000
Pembroke low level subsoil water, average quantity pumped per day for the last 6 months	815,000
Two streams entering the Rathmines sewers (dry weather gaugings)	280,000
Balance, being subsoil and land water from Pembroke high level district and from Rathmines	2,555,000
	6,190,000

As regards these figures it must be remarked that the Rathmines sewage is only about three-fourths the strength of ordinary sewage, as it is calculated at the rate of 44 gals. per head per day, which is the actual water consumption, whereas standard sewage is taken at 30 gals. per head per day, and the Pembroke sewage is also largely diluted, as it is calculated at the rate of 40 gals. per head per day, which is the actual water consumption.

The liquid discharged therefore consists of standard sewage in the following proportions:—

	Gallons.
Standard sewage, Rathmines, population 35,000 at 30 gallons per head	1,050,000
Standard sewage, Pembroke, 25,000 at 30 gallons per head	750,000
Water	4,390,000
	6,190,000

The sewage, therefore, as discharged from this outfall is less than $\frac{1}{3}$ the strength of ordinary standard sewage. The actual figure is 29 per cent. standard sewage and 71 per cent. land and subsoil water.

The heavier solids are retained within the system of main sewers by means of the catch-pits already refered to, and are thus prevented from being discharged with the main body of the sewage from the outfall. The quantity of solids retained by these catch-pits has been measured, and it has been found to amount to 2 tons in the wet state, or $1\frac{1}{3}$ ton in the dry state, per day. The solids thus separated principally consist of road detritus, gravel, sand and the heavier constituents of the suspended matters of the sewage.

According to the Rivers Pollution Commission, average town sewage contains about 1 ton of suspended mineral matter per million gallons. As the quantity of standard sewage is about 1,750,000 gallons, the quantity of mineral solids in suspension would be $1\frac{3}{4}$ ton; of this $1\frac{1}{3}$ ton is removed at the catch-pits, including all the heavier solids which would cause trouble in the estuary by forming banks along its bed, and less than $\frac{1}{2}$ ton of mineral suspended matter is discharged per day.

The results of analysis of 23 samples, which were collected both from the bottom and surface of the sewage in the Penstock chamber of the outfall works, are recorded in the succeeding table 4. These analyses show that that the sewage is between $\frac{1}{3}$ and $\frac{1}{4}$ the strength of the average of 50 samples of sewage from 16 towns recorded in the first report of the Rivers Pollution Commission, p. 29.

Table 4.—Analyses of Samples of Sewage collected from the Penstock Chamber of the Rathmines and Pembroke Main Drainage Outfall Works.

No.	Date and Time of Collection.	Weather.	High water. Morning.	Time kept.†	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of sewage.			Other constituents as parts by weight per 100,000 parts of sewage.						
								Nitrogen as					Solids in suspension.	
					Carbon dioxide.	Oxygen.	Nitrogen.	Ammonia.	Nitrates and Nitrites.	Organic.	Chlorine.	Solids in solution.	Mineral.	Organic.
	1899.													
1	March 16 - 2.20 p.m. -	Extremely dry.	1.58 (p.m.)	21 hours.	95·10	0·00	16·41	0·25	0·464	·392	217	471	Traces.	
2	„ 16 - 5.15 „ -	„	„	16 „	119·40	0·00	18·77	4·00	0·000	1·992	148	338	42·4	
	1900.													
3	Jan. 11 - 11.25 a.m. -	Wet.	7.7	5 „	127·60	4·02	16·21	1·10	·650	·35	140	343	22·69	13·31
4	„ 17 - 12.25 p.m. -	„	12.15 (p.m.)	3 „	107·93	2·32	16·61	0·50	·455	·20	112	267	13·59	2·01
5*	„ 17 - 1.5 „ -	„	„	4 „	126·90	0·22	17·65	0·72	·065	·48	66·5	184	47·54	7·46
6	„ 26 - 11.50 a.m. -	„	6.6	3 „	118·20	1·71	16·29	2·25	·150	·98	157·5	352	2·19	0·66
7*	„ 26 - 11.55 „ -	„	„	4 „	118·12	1·63	16·28	2·25	·176	·98	157·5	366	2·54	0·26
8*	„ 29 - 2.25 p.m. -	„	9.37	2 „	131·03	1·07	16·88	2·40	·11	1·00	150·5	344	8·77	7·43
9	„ 29 - 2.30 „ -	„	„	3 „	131·07	1·52	18·40	2·70	·10	·90	154	352	6·77	6·83
10	March 2 - 3.50 „ -	Dry.	11.32	22 „	129·20	0·00	18·42	1·13	·77	·47	175	424	3·57	8·65
11*	„ 2 - 3.53 „ -	„	„	23 „	129·80	0·00	18·50	1·13	·82	·27	172	414	4·47	9·93
12*	„ 9 - 9.0 a.m. -	Very dry.	4.55	3 „	113·73	3·83	16·75	0·30	·75	·13	191	446	1·135	3·365
13*	„ 9 - 10.16 „ -	„	„	8 „	111·47	3·14	16·79	0·25	1·00	·20	182	424	Traces.	
14*	„ 10 - 11.5 „ -	„	6.15	3 „	117·36	1·94	17·14	1·06	·34	·49	156	369	1·385	2·015
15*	„ 10 - 12.5 „ -	„	„	5 „	115·85	1·07	17·55	1·02	·73	·58	158	362	0·485	1·415
16*	„ 12 - 1.0 p.m.	„	8.45	3 „	121·28	1·09	17·66	1·70	·55	1·25	140	331	1·985	8·515
17*	„ 12 - 2.0 „ -	„	„	3 „	123·54	0·19	18·00	1·60	·50	1·05	140	326	2·015	1·485
18*	„ 13 - 3.0 „ -	„	9.37	19 „	144·78	0·00	21·19	2·85	·30	·35	152	324	0·390	6·600
19*	„ 13 - 4.0 „ -	„	„	20 „	144·75	0·00	20·99	3·00	·35	·45	149	338	1·285	4·315
20*	„ 14 - 5.0 „ -	„	10.16	17 „	143·64	0·00	20·96	2·90	2·20	·30	158	347	2·085	3·385
21*	„ 14 - 6.0 „ -	„	„	20 „	144·71	0·00	20·84	3·00	2·40	·30	158	366	0·985	5·515
22*	„ 15 - 3.10 „ -	„	10.45	2 „	135·09	0·00	19·11	2·85	2·70	·85	166	426	6·0	13·300
23*	„ 16 - 3.15 „ -	„	11.3	2 „	133·80	0·00	18·59	1·80	3·45	1·55	187	426	6·7	13·700
	Average - - - - - - - - - - - - - - - - - -							1·73	0·827	0·67	151	363	6·88	6·15
	Average of 50 samples from 16 towns ("Reports of the Rivers Pollution Commission") - - -							6·703	0·003	2·205	10·66	72·2	24·18	20·51

* Samples marked with an asterisk (*) were collected from the bottom of the sewage in the Penstock Chamber, the other samples were collected from the surface of the sewage.

† The bottles in which the samples were collected were completely filled and carefully stoppered, so as to leave no air in them, and their contents were preserved from contact with air until they were analysed. The number of hours each sample was kept is given in this column.

The suspended matters were all of a light flocculent character, with the exception of Nos. 3 and 5, the suspended matters in which were chiefly fine clay and sand. No heavy mineral matters were found in any of the samples.

All the samples contained nitrites with exception of No. 2.

All the samples were free from odours of putrefaction; this was owing to the large quantities of nitrates present in them.

The results of analysis of a second series of samples, which were collected from the bottom of the Penstock chamber in April, 1905, have already been recorded.*

The results of these analyses show that the samples contained a little more ammonia and a little less nitrates and nitrites than the first series. No doubt these variations in composition were largely due to the different states of weather which prevailed when the samples were collected. It was predominantly very dry when the first series were collected, and predominantly wet during the time of collection of the second series.

The two series were also, it should be noted, not quite comparable. Each sample of the second series was an average of samples hourly collected from the bottom of the Penstock chamber, from half an hour after the gates were opened to half an hour after they were closed. The samples of the first series were not average samples, and they were moreover collected both from the bottom and from the surface of the sewage in the Penstock chamber. The analyses however of both series of samples show that the sewage as discharged from the outfall is extremely weak, and that it possesses two further characteristics which are also quite exceptional as regards ordinary town sewage. These are—(1) nitrates and nitrites, derived from the subsoil water, are present in exceptionally large quantities; (2) the suspended matters are all of a light character. The mineral matter consists of light sand and clay, and the organic matters are of a light flocculent character. Heavy road detritus or other heavy suspended matters have not been observed in the sewage in the Penstock chamber, even during very heavy rain after some days of dry weather. The presence of the large quantities of nitrites and nitrates explains the circumstance which has frequently attracted attention, viz., the absence of offensive odours of putrefaction in the Penstock chamber even in dry and warm weather. The removal of the heavier solids from the sewage before discharge from the outfall also explains the absence of offensive sludge banks in the neighbourhood of and below the outfall. The sewage solids which are discharged from the outfall are of so light and flocculent a nature as to be easily borne for long distances by the estuary waters before subsidence. They do not consequently form permanent accumulations in any part of the bed. Nevertheless these solids should not be allowed to be discharged from this outfall since, when northerly winds prevail, an unsightly accumulation of floating matters of various kinds such as corks, paper, vegetable refuse, cinders, and in fact all matters inseperable from domestic sewage, are formed along the shore immediately under the south wall at low states of the tide. It is probable they could be successfully removed by means of fine screens.

THE EFFECT OF THE SEWAGE UPON THE WATERS OF THE ESTUARY.

(*a*) *High Tides.*

When at high water the valves of the Penstock chamber are first opened, the invert of the outfall is 10 to 14 feet below the surface of the estuary water, according to the tidal season. The sewage rushes up through this depth of water with some violence to the surface, and in calm weather spreads out in a narrow stream and floats with the tide in an almost straight line to the mouth of the estuary and thence into the bay.

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* Section on Chemical Changes, etc., p. 66.

For the first series of samples which were collected by Mr. Kaye-Parry and one of the authors, the path of the sewage was determined by means of three floats. Samples of water were collected vertically over the outfall, and at the same time three floats were placed in the water. Further samples were then collected in the path of the float at intervals of about half an hour, until the floats passed the mouth of the estuary into the bay, which they did in 1 hour 15 minutes after having been placed in the water over the outfall.

From the analyses which are given in the succeeding table 5 it will be observed that the sewage during its passage from the outfall to the surface of the estuary immediately above it became diluted with about five times its bulk of sea water, and that this mixture must have flowed with the tide in a narrow stream to the mouth of the estuary with but little further dilution. Perhaps it would be more accurate to say that the central portions of the stream were but little further diluted. The weather at the time was perfectly calm, and the ebb tide had well set in when the first sample over the outfall was collected. The analyses in this table also show that even the central portions of the stream of mixed sewage and tidal water, as it flowed away from the outfall, was practically innocuous. It is evident in fact that if the samples had not been kept out of contact with the air until they were analysed no loss of oxygen would have been discovered.

TABLE 5.—ANALYSES OF SAMPLES OF ESTUARY WATER COLLECTED DURING THE FIRST TWO HOURS OF THE EBB (AVERAGE TIDE), MARCH 16TH, 1899.

Samples collected along the path of the sewage (shown by floats) after discharge from the Outfall. Weather extremely dry and calm. High tide 1.58 p m. Valves of Penstock Chamber opened at 2.20 p.m.

No.	SURFACE SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.				
							Nitrogen as				
			Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Total Solids.
		Hours.									
	Sewage from Penstock Chamber (see Table 4) -	21	95·10	0·00	0·0	16·41	·25	·464	·392	217	471
1	In mid-stream opposite Pigeon House Harbour at 2 p.m. - - - -	24	46·67	6·53	2·1	12·76	·01	·030	·038	2,030	3,655
2	Over the Outfall in the path of sewage at 2.37 p.m. -	26	55·83	5·62	15·8	13·28	·05	·085	·064	1,890	3,147
3	Below Outfall in path of sewage at 3 p.m. - -	42	52·83	5·50	17·6	13·06	·05	·130	·190	1,750	3,310
4	Below Outfall in path of sewage at 3.30 p.m. -	44	52·33	5·56	16·7	12·95	·06	·160	·190	1,750	3,128
5	Below Outfall in path of sewage and between the Lighthouses at 3.52 p.m.	96	51·26	5·39	19·3	12·93	·05	·100	·146	1,750	3,216
6	In Dublin Bay S. of Poolbeg Light at 4 p.m.	96	46·19	6·68	0·0	12·99	·0005	·010	·009	1,995	3,794

* The figures in this column indicate the percentage loss of dissolved atmospheric oxygen in the samples after keeping them for the periods of time given in the third column, the maximum quantity of oxygen which the samples could hold in solution in an unpolluted condition being taken as one-half that of the atmospheric nitrogen which they contained (see seventh column).

All the samples, except No. 6, were slightly turbid and odourless, and contained traces of flocculent matters in suspension. It was quite clear, odourless, and contained minute traces of fine granular matters in suspension.

TABLE 6.—ANALYSES OF SAMPLES COLLECTED AT THE COMMENCEMENT OF THE EBB (SPRING TIDE) JANUARY 17, 1900.

Weather showery; strong west wind. High tide 12.4 *p.m.*

No.	SURFACE SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N. T. P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.					
							Nitrogen as				Solids in	
			Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solution.	Suspension.
		Hours.										
	Sewage (see Table 4, No. 4) - -	3	107·93	2·32	—	16·61	·500	·455	·200	·112	267	15·601
1	Over Outfall in path of sewage, at 12.30 p.m., very turbid owing to clay and fine sand in suspension - -	23	64·08	6·03	9·66	13·62	·175	·235	·125	1365	2553	2·400
2	Above Outfall, near the Black Buoy 2, at 12.35 p.m. Slightly turbid - -	27	48·08	6·42	3·82	12·87	·003	·035	·017	2118	3518	traces.
3	Below Outfall, near mid-channel, about one-third way to Lighthouses, at 12.40 p.m. Slightly turbid -	48	46·33	6·34	5·02	12·94	·002	·008	·018	1761	3522	traces.
4	Below Outfall in path of sewage one-third way to Lighthouses, at 12.45 p.m. Slightly turbid -	50	48·05	6·38	4·42	12·91	·004	·013	·012	1709	3530	traces.
5	Below Outfall, on South side of path of sewage and one-third way to Lighthouses. Distinctly turbid -	52	48·19	6·20	7·12	13·02	·014	·022	·067	1820	3628	traces.

* See footnote, Table 5.

The analyses in Table 6 indicate the effect of the sewage when discharged at high spring tides under a strong west wind. It is evident from them that the effect upon the aeration of the estuary waters would have been inappreciable had not the samples been kept out of contact with the air.

It should be noted that the samples of water referred to in these tables had been polluted by sewage from Dublin as well as by that from the townships' outfall. It may be concluded, therefore, that both sewages together are insufficient to pollute the waters of the estuary at the points where the samples were collected, to the maximum limit allowable under the proposed standard for second class tidal waters.†

(*b*) *Low Tides.*

The polluting effect of the sewage upon the bottom and surface waters of the Estuary during the last two hours of the neap ebb and spring ebb tides, under calm and dry weather conditions, is demonstrated by the analytical results recorded in the succeeding Tables 7 and 8.

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† Section on Chemical Changes, etc., pp. 91–96.

The analyses of Samples Nos. 1, 3, 5 and 7, Table 7, when compared with that of the sewage collected just before from the bottom of the Penstock chamber, show that the latter, on flowing from the outfall to the surface of the water overlying it became diluted with about an equal volume of estuary water, and that at a distance of 10 yards from the outfall the dilution had increased to about six volumes, at 50 yards distance to about seven volumes, and at 100 yards to about ten volumes, of estuary water to one volume of sewage.

The analyses of the bottom samples indicate very slight pollution at a distance of 10 yards from the outfall, and at a depth of only 2 feet. On comparing them with those of the surface samples, and with those of the samples collected outside the path of the sewage, it becomes evident that the bottom water even when only 2 to 4 feet below the surface and in the path of the sewage for a distance of at least 100 yards, is but slightly affected by the sewage from the outfall.

On referring to the aeration of the samples which had been collected a hundred yards below the outfall, and in the path of the sewage, and after they had been kept out of contact with the air for seven days, it will be noticed that it amounts to 5·35 cc. oxygen in the bottom sample, and 4·8 cc. oxygen in the surface sample, per litre. It will be seen from these figures that the pollution caused by the sewages from the outfall at only 100 yards distance is extremely slight, and well within the suggested standard for the second class of tidal waters already referred to.

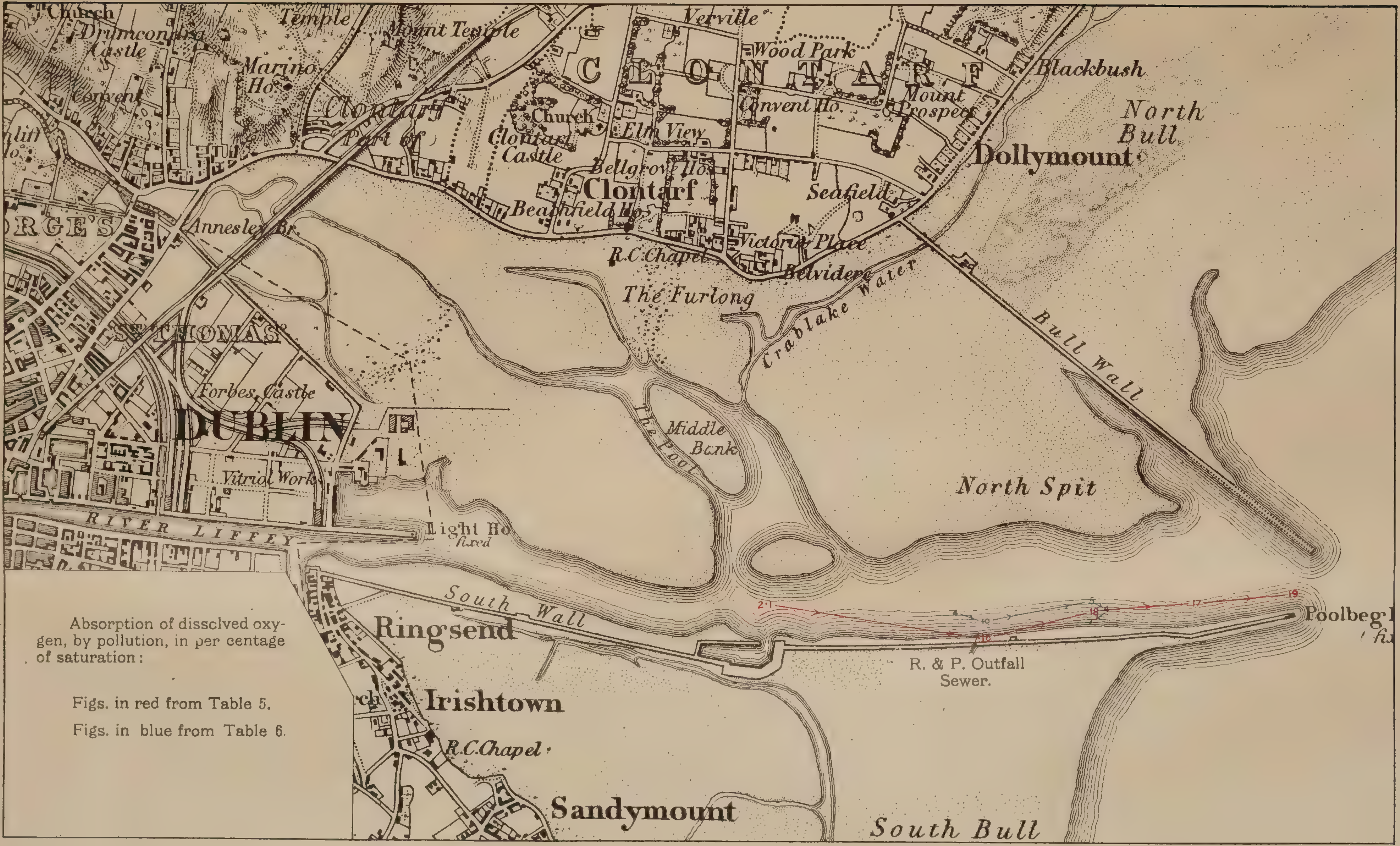
The analytical results recorded in Table 8 indicates a similar freedom from serious pollution of the estuary waters during the fifth hour of the spring ebb tide in calm weather.

It is evident therefore that the discharge from this outfall could be allowed under existing conditions in accordance with the suggested standard for the second class of tidal waters but for the fact that the samples contained solids in suspension to an extent which is inadmissable under the standard, and although the solids are too light to form permanent accumulations anywhere, they do form temporary deposits along the closely adjacent shore under the south wall with northerly winds during the lower states of the tide. It is true that they are broken up and widely dispersed by the ensuing flood tide, but consisting, as they do, of paper, vegetable dêbris of various kinds, corks, cinders, and other floating matters inseparable from domestic sewage, they are most unsightly, if not actually offensive, and they should not be allowed to be discharged with the liquid sewage from the outfall. The authors believe they could be sufficiently removed by means of good revolving wire screens of fine mesh, the installation of which would not necessitate the outlay of a large sum of money.

C.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Map to illustrate Dr. Adeney's Section on the Liffey Estuary.



Absorption of dissolved oxygen, by pollution, in per centage of saturation:

Figs. in red from Table 5.

Figs. in blue from Table 6.

Ordnance Survey, Southampton.

TABLE 7.—ANALYSES OF SAMPLES OF ESTUARY WATER COLLECTED DURING THE LAST TWO HOURS OF THE EBB (NEAP TIDE), MARCH 9TH, 1900.

High Water at 4.55 a.m. Weather very dry and calm; no rain for the previous seven days, with light E. and N.-E. winds.

No.	SURFACE AND BOTTOM SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N. T. P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
			Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Nitrogen as			Chlorine.	Solids in solution.	Solids in suspension.	
							Ammonia.	Nitrates.	Organic.			Inorganic.	Organic.
	Sewage (No. 12, Table 4)	3 hrs.	113·73	3·83	0·00	16·75	·300	·750	·130	191	446	1·135	3·365
1	Over Outfall at 9.5 a.m.	4 „	85·05	5·27	31·16	15·31	·160	·340	·060	837	1,651	1·285	0·715
2	10 yards below Outfall in path of sewage, and 2 feet below surface, at 9.9 a.m.	5 „	53·73	6·24	10·24	13·90	·004	·051	·086	1,575	3,057	Traces.	
3	Ditto at surface, at 9.12 a.m.	6 „	63·20	5·95	17·78	14·47	·042	·158	·088	1,295	2,527	Traces.	
4	50 yards below Outfall, and 2 feet below surface, at 9.14 a.m., in path of sewage	30 „	54·27	6·15	13·26	14·17	·015	·013	·045	1,554	3,066	Traces.	
5	Ditto at surface, at 9.17 a.m.	31 „	60·96	5·77	20·28	14·48	·042	·083	·010	1,313	2,565	Traces.	
6	100 yards below Outfall, and 4 feet below surface, in path of sewage, at 9.19 a.m.	7 days	52·97	5·35	23·68	14·02	·012	·028	·042	1,617	3,135	Traces.	
7	Ditto at surface, at 9.22 a.m.	7 „	61·27	4·80	32·68	14·26	·032	·086	·038	1,348	2,614	Traces.	
8	Mid-way between Outfall and mouth of Harbour, near the south wall, 7 feet below the surface, at 9.30 a.m.	10 „	50·47	6·11	12·46	13·96	·006	·016	·054	1,663	3,280	Traces.	
9	Ditto at surface, at 9.32 a.m.	10 „	59·27	4·37	38·71	14·26	·015	·035	·064	1,400	2,711	Traces.	
10	Mid-way between Outfall and mouth of Harbour, and a little to north of path of sewage, 7 feet below the surface, at 9.34 a.m.	10 „	50·27	5·79	16·57	13·88	·001	·012	·036	1,694	3,295	Traces.	
11	Ditto at surface, at 9.37 a.m.	10 „	56·93	4·83	32·59	14·30	·004	·028	·058	1,400	2,742	Traces.	
12	In deep channel, near Lightbuoy 1, 21 feet below the surface, at 9.40 a.m.	11 „	48·97	6·49	7·55	14·04	·007	·014	·016	1,768	3,457	Traces.	
13	Ditto at surface, at 9.53 a.m.	11 „	57·85	4·77	32·44	14·13	·016	·031	·040	1,335	2,670	Traces.	
14	100 yards above Outfall, mid-way between south wall and deep-water channel, 7 feet below the surface, at 10.10 a.m.	11 „	55·12	5·11	27·31	14·07	·017	·026	·038	1,523	2,904	Traces.	
15	Ditto at the surface, at 10.13 a.m.	11 „	65·51	3·16	56·77	14·62	·034	·055	·048	1,155	2,742	Traces.	

* *See* footnote to Table 5.

TABLE 8.—ANALYSES OF SAMPLES OF ESTUARY WATER COLLECTED DURING THE LAST TWO HOURS OF THE EBB (SPRING TIDE), ON MARCH 2ND, 1900.

Weather fine, no rain during the previous 48 hours; light N.-W. wind. High tide 11.32 *a.m.*

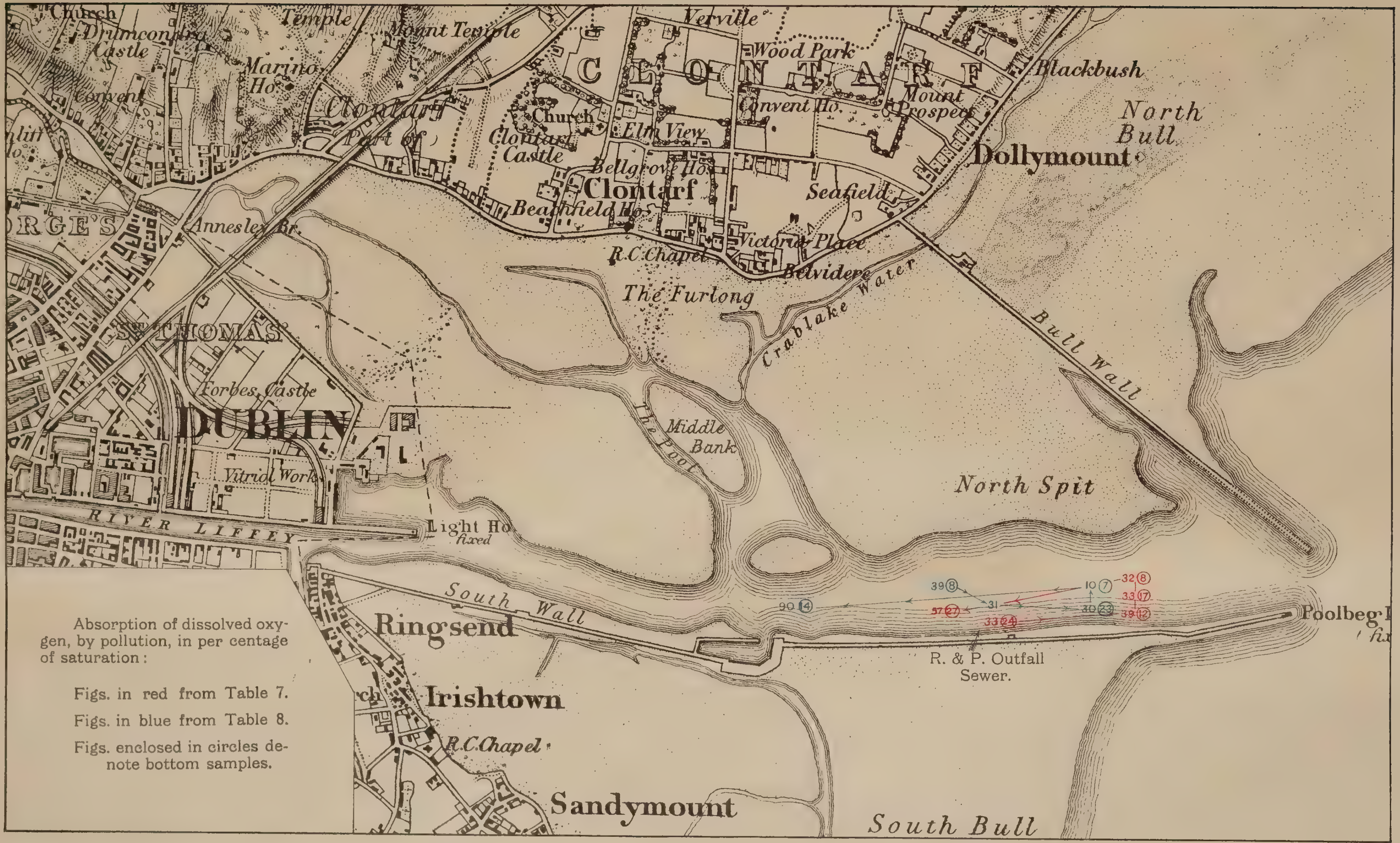
No.	SURFACE AND BOTTOM SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N. T. P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
			Carbon dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Nitrogen as			Chlorine.	Solids in solution.	Solids in suspension.	
							Ammonia.	Nitrates.	Organic.			Mineral.	Organic.
	Sewage from Penstock chamber. Very turbid - - -	23 hours	129·80	0·00	0·00	18·50	1·13	·82	·270	172	414	4·47	9·93
1	Over Outfall, at 4.5 p.m. Turbid; odourless - - -	19 hours	125·80	1·01	88·31	17·25	1·00	·80	·150	210	486	3·97	6·03
2	100 yards above Outfall, near Buoy 2, in mid-channel, 15 feet below surface, 4.10 p.m. Clear; odourless - - -	4 days	51·41	6·60	8·08	14·35	·000	·024	·062	1,631	3,169	5·14	1·265
3	Ditto, at the surface. Distinctly turbid; odourless - -	4 days	62·07	4·70	39·28	15·48	·003	·065	·071	921	1,829	traces.	
4	100 yards below Outfall, near the S. Wall, at 4.20 p.m., in shallow water. Turbid; odourless - - - - - -	20 hours	69·41	5·21	30·66	15·03	·080	·420	·170	980	1,906	2·47	1·73
5	Below Outfall, midway between the S. Wall and the Light-buoy 1, 14 in. below surface, at 4.28 p.m. Turbid; odourless - - - - - - - - - - -	3 days	55·12	5·73	23·40	14·96	·003	·088	·037	1,267	2,484	1·28	0·32
6	Ditto, at surface, 4.30 p.m. Turbid; odourless - - -	3 days	56·53	5·19	29·96	14·83	·004	·056	·060	1,250	2,411	0·63	0·00
7	Mid-channel, near Light-buoy 1, 14 feet below the surface, at 4.35 p.m. Clear; odourless - - - - - -	4 days	51·03	6·67	6·71	14·30	·002	·024	·034	1,503	3,151	2·885	2·215
8	Ditto, at surface, 4.37 p.m. Slightly turbid; odourless -	4 days	55·96	5·98	10·41	14·84	·004	·026	·034	1,330	2,602	traces.	
9	Above Outfall, mid-channel, opposite Pigeon House Harbour, 14 feet below surface, at 5.22 p.m. Faintly turbid; odourless - - - - - - - - - - -	5 days	51·34	6·18	13·63	14·31	·018	·007	·036	1,579	3,098	3·885	1·715
10	Ditto, at surface, at 5.26 p.m. Turbid; odourless - -	5 days	72·61	0·82	90·10	16·48	·120	·070	·130	459	929	traces.	

* See footnote, Table 5.

D.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Map to illustrate Dr. Adeney's Section on the Liffey Estuary.



Absorption of dissolved oxygen, by pollution, in per centage of saturation:

Figs. in red from Table 7.

Figs. in blue from Table 8.

Figs. enclosed in circles denote bottom samples.

Ordnance Survey, Southampton.

Solids in Suspension.—The solids in the bottom water samples were of a light granular character, those in the surface water samples were of a very fine granular character with occasional pieces of light flocculent matter.

GENERAL CONDITION OF THE ESTUARY WATERS AT LOW TIDES AND IN CALM AND DRY WEATHER.

(*a*) *Spring Tides.*

Some of the samples, the analyses of which are recorded in Table 8, show the condition of the estuary waters both above and below the townships' outfall during an exceptionally low spring tide.

Samples 2 and 3 were collected 4½ hours after high water, 15 feet below the surface and at the surface respectively, in the deep water channel at a point 1,122 yards below the Pigeon House Harbour (fig. 1) and a short distance above the outfall. Samples 7 and 8 were collected 30 minutes later, near buoy No. 1, 14 feet below the surface and at the surface respectively. The points where these, and the other samples which will be referred to, were collected, will be found marked upon the map which accompanies Table 8, Buoy No. 1, is about 1,870 yards below the Pigeon House Harbour. Samples 9 and 10 were collected opposite the Pigeon House Harbour from the bottom (14 feet below the surface) and from the surface, respectively, of the deep water channel, 72 minutes later than samples 2 and 3, and a few minutes before low water at Dublin Bar.

The volumes of carbon dioxide, oxygen and nitrogen in these three sets of samples, after they had been kept 4 to 5 days out of contact with the air, clearly show the influence of the Dublin sewage upon the bottom and surface waters of the estuary, thus :—

—	Bottom Samples.				Surface Samples.			
	No.	Carbon Dioxide.	Nitrogen.	Oxygen in per cent. of saturation.	No.	Carbon Dioxide.	Nitrogen.	Oxygen in per cent. of saturation.
Opposite the Harbour -	9	51·3	14·3	86·4	10	72·6	16·5	9·9
1,122 yards below „ -	2	51·4	14·3	91·9	3	62·1	15·5	60·7
1,870 yards below „ -	7	51·0	14·3	93·3	8	56·0	14·8	89·6

These figures show that the bottom waters of the estuary along the deep water channel are fairly uniform in composition, and are but slightly polluted from abreast of the Pigeon House Harbour downwards, even during a state of the tide when the volume of sea water is at a minimum. The samples collected abreast of the Pigeon House Harbour show a loss of oxygen amounting to only 13·6 per cent. of that required for saturation, after having been kept out of contact with air for five days. The figures for the surface samples, on the other hand, exhibit considerable differences in composition and in degree of pollution. Thus, opposite the harbour, the loss of oxygen amounts to 90·1 per cent. of saturation, after keeping the sample out of contact with air for five days, whilst 1,122 yards lower down the loss amounts to 39·3 per cent., and 748 yards still farther down the deep water channel it is only 10·4 per cent.

The other determinations recorded in Table 8 confirm these conclusions. Thus the amount of dissolved nitrogen in the bottom samples is practically uniform, showing that the ratio of fresh water to sea water was very similar in all three samples, whilst it differs considerably in the surface samples, indicating a large difference in the relative quantities of river water and sea water.

It is possible to estimate, with close approximation to the truth, the ratio of mixed river water and sewage to sea water in each sample from the figures giving the quantities of total solids, taking the total solids of mixed river water and sewage at 50 parts, and of the sea water at 3,655 parts per 100,000, thus:—

——	Bottom Samples.			Surface Samples.		
	No. of sample.	Total solids.	Ratio of river water to sea water.	No. of sample.	Total solids.	Ratio of river water to sea water.
Opposite the Harbour	9	3,098	1:5	10	929	3:1
1,122 yards below „	2	3,169	1:6·4	3	1,829	1:1
1,870 yards below „	7	3,151	1:6	8	2,602	1:2·4

The foregoing tabular statements become all the more instructive when it is remembered that the Pigeon House is fully two miles below the outfalls of the principal Dublin sewers. It is apparent from the data which they afford, that in calm weather the mixing of the sewage and river water with the sea water takes place extremely slowly in a downward vertical direction, but more rapidly in lateral directions.

(*b*) *Neap Tide.*

The samples recorded in the ensuing Table 9 were collected at low water, and at the commencement of the flood, of a neap tide, in perfectly calm and dry weather conditions.

Particular interest attaches to the analyses of these samples, because it is generally believed by those intimately acquainted with the estuary that large quantities of sewage remain within the estuary at low neap tides, and that in addition considerable quantities are brought back into the estuary with the ensuing flood tide and are carried over to the Clontarf strand. The samples were collected from the lower portions of the estuary with the special object of ascertaining whether there are any real grounds for this belief. The atmospheric conditions were all that could be desired for the purpose. The weather was quite calm and had been so for some time previously, and it was dry and frosty.

TABLE 9.—ANALYSES OF SAMPLES OF ESTUARY WATER COLLECTED AT LOW WATER (NEAP TIDE), AND AT THE COMMENCEMENT OF THE FLOOD TIDE, FEBRUARY 9TH, 1900.

High water 5.24 a.m. Weather dry and frosty, and quite calm.

No.	SURFACE SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.				
							Nitrogen as				
			Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Total Solids.
		Days.									
1	Below Outfall, two-thirds the way down, near South Wall, at 11.25 a.m.	10	69·09	4·71	40·53	15·84	·050	·068	·028	1,094	2,096
2	Below Outfall, two-thirds the way down in mid-stream, at 11.30 a.m.	10	59·97	5·91	18·45	14·49	·025	·048	·029	1,419	2,709
3	Below Outfall, near Bull Lighthouse and within the harbour at 11.40 a.m.	10	53·84	6·04	12·97	13·91	·003	·037	·033	1,627	3,150
4	Below Outfall, mid-channel and between Lighthouses, inside Harbour, at 11.45 a.m.†	10	58·03	5·75	20·91	14·54	·012	·026	·036	1,522	2,926

* See footnote, Table 5.

† The flood tide had just commenced to set in at this time.

TABLE 9.—Analyses of Samples of Estuary Water collected at Low Water (Neap Tide), and at the commencement of the Flood Tide, February 9th, 1900—(*continued*).

No.	SURFACE SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.				
							Nitrogen as				
			Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Total Solids.
		Days.									
5	Below Outfall, near Poolbeg Lighthouse, within the Harbour, at 11.50 a.m.	11	54·50	5·77	17·28	13·95	·010	·021	·044	1,631	3,166
6	Outside Harbour, to North and close to the Bull Lighthouse, at 11.55 a.m.	11	49·81	6·27	7·74	13·60	·005	·020	·025	1,768	3,402
7	Below Outfall, inside Harbour, near Bull Lighthouse, at 12.12 p.m.† -	12	53·41	6·08	12·77	13·94	·005	·017	·035	1,680	3,266
8	Outside Harbour, to North and near Bull Lighthouse, at 12.16 p.m. -	12	48·79	6·17	8·86	13·54	·002	·019	·036	1,785	3,475
9	Inside Harbour, in mid-channel between Lighthouses, at 12.20 p.m. -	12	56·75	5·81	18·91	14·33	·007	·028	·023	1,533	2,997
10	Inside Harbour, near Poolbeg Lighthouse, at 12.25 p.m. - - -	12	54·73	5·46	21·94	13·99	·007	·033	·043	1,640	3,213
11	Midway between the Outfall and Lighthouses, near South Wall, at 12.35 p.m. - - -	13	68·74	4·81	38·17	15·56	·020	·055	·040	1,026	2,001
12	Midway between the Outfall and Lighthouses, in mid-channel at 12.42 p.m.	13	58·71	5·58	22·50	14·40	·004	·046	·038	1,444	2,826
13	River Liffey, above Chapelizod - - - - -	17	42·68	5·20	33·33	15·59	·004	·037	·045	1·26	18
14	Mid-channel, abreast Pigeon House‡ - - - -	Hours. 24	62·41	3·70	49·07	14·53	·020	·090	·033	1,575	2,439
15	Mid-channel, between the Lighthouses‡ - -	23	51·56	6·56	3·24	13·57	·010	·005	·011	1,750	3,338
16	North of Channel, abreast Pigeon House, at half flood tide (H.W. 12 p.m.) S.W. wind, 29th March, 1899 - - -	28	48·11	6·29	1·70	12·52	0·02	0·015	0·01	1,750	3,328
17	Ditto at low water, 1st April, 1890, West wind	Days. 7	51·9	4·92	21·7	12·57	0·01	0·015	0·01	1,730	3,328

* See footnote, Table 5

† The flood tide had well set in at this time.

‡ These samples were collected on March 24th, 1899: the first, 5 hrs. 50 m. after high water; the second, 25 minutes after low water. Weather extremely dry, fresh west wind.

The tidal movements of the water were plainly shown by the movement of the light cinders which floated on the surface of the water both inside and outside the Harbour. There was no other movement of the water to disturb them. Both air and water were perfectly calm.

The more important of the foregoing analytical results are grouped in the following tabular statement in a manner which shows at a glance the composition and degree of pollution of the surface waters in different parts of the estuary below the Pigeon House.

It will be observed that the loss of oxygen from pollution in the samples collected from the surface of the deep water channel in no case reaches 23 per cent. notwithstanding the fact that the samples were kept out of contact with the air for 10 to 13 days.

Such a loss would not have shown itself if the samples had been exposed to the air. It may therefore be concluded that the pollution of the surface water of the channel in the estuary during a low neap tide is so slight that it can only be ascertained when the water is subjected to the most rigorous conditions for the detection of pollution.

If this be true of the surface water it may also be inferred from the evidence afforded by Table 8 that the bottom water of the deep water channel of the estuary is practically unaffected by the Dublin sewage.

It is plain also that the incoming flood tide does not bring back sewage matters to an appreciable extent into the estuary and carry them on to the Clontarf strand. As a matter of fact the surface water on the Clontarf side of the deep water channel happens to have been the least polluted of the estuary waters during most of the occasions on which they have been examined. The results of analysis of the waters of the estuary therefore confirm those of the analysis of the bed of the estuary which have already been considered, pp. 277–279.

No.	Where collected.	When collected.	Carbon dioxide.	Nitrogen.	Degree of Pollution.*	Total Solids.	Ratio of River to Sea-water.
	Deep-water Channel.						
21	1,930 yards below Pigeon House Harbour	At low water.	60·0	14·5	18·4	2,709	1 : 2·9
12	1,450 „ „ „	70 minutes later.	58·7	14·4	22·5	2,826	1 : 3·4
	Shallow water, South of Deep-water Channel.						
1	1,930 yards below Pigeon House Harbour	At low water.	69·1	15·8	40·5	2,096	1 : 1·3
11	1,450 „ „ „	70 minutes later.	68·7	15·6	38·2	2,001	1 : 1·2
	Mouth of Harbour.						
3	North side of Channel - -	Just at the turn of the tide.	53·8	13·9	13·0	3,150	1 : 6·0
4	Mid-channel - - - - -		58·0	14·5	20·9	2,926	1 : 4·0
5	South side of Channel - -		54·5	13·9	17·3	3,166	1 : 6·3
7	North side of Channel - -	30 minutes later.	53·4	13·9	12·8	3,266	1 : 8·3
9	Mid channel - - - -		56·7	14·3	18·9	2,997	1 : 4·5
10	South side of Channel - -		54·7	14·0	21·9	3,213	1 : 7·3
	Outside Harbour.						
6	North side of Channel - -	30 minutes after low water.	49·8	13·6	7·7	3,402	1 : 14·0
8	North side of Channel - - -	20 minutes later.	48·8	13·5	8·9	3,475	1 : 20·0

* See footnote, Table 5, p. 284.

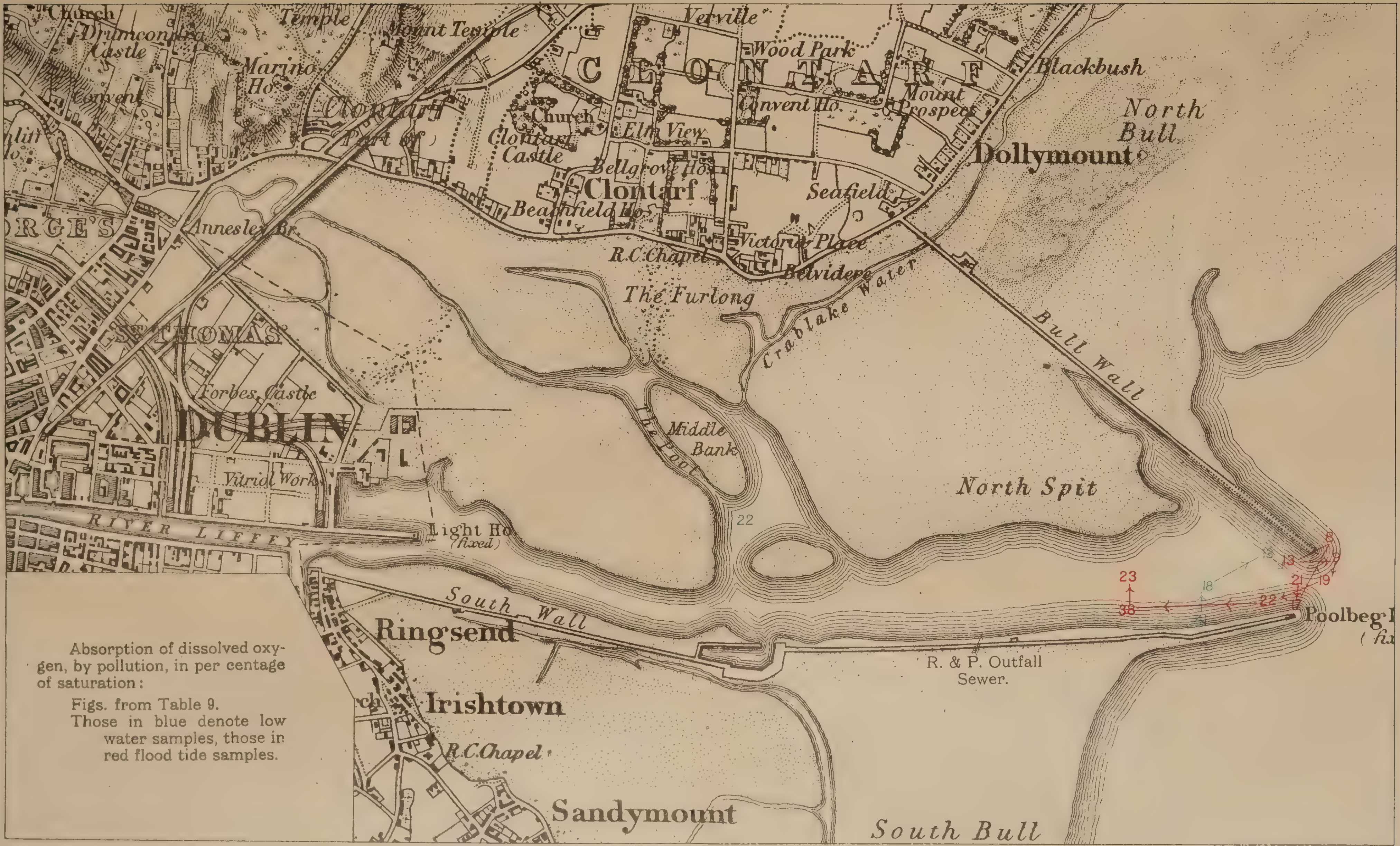
Further evidence in support of these statements will be found on referring to the analyses of the two surface Samples 16 and 17 recorded in Table 9. These samples were collected from the north side of the deep water channel on March 29th and April 1st of the preceding year (1899). The former sample was collected during a half flood spring tide, and the latter at low water, both abreast of the Pigeon House Harbour. The half flood tide sample after having been kept for 28 hours showed a loss of oxygen amounting to 1·7 per cent. of the volume required for saturation, and the low water sample a loss of 21·7 per cent. of the saturation volume after having been kept out of contact with air for 7 days.

Reference to the results given for the Samples 1 and 11 in the tabular statement, and for 14 and 15 in Table 7 shows that the most polluted portion during low neap tides is the shallow portion to the south of the deep water channel stretching from the Pigeon House Harbour to the Poolbeg Lighthouse.

E.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Map to illustrate Dr. Adeney's Section on the Liffey Estuary.



Absorption of dissolved oxygen, by pollution, in per centage of saturation:

Figs. from Table 9.
Those in blue denote low water samples, those in red flood tide samples.

Ordnance Survey, Southampton

Samples 14 and 15, Table 7, were collected 7 feet below the surface, and at the surface, respectively, of the shallow water lying between the south wall and the deep water channel, and abreast of buoy No. 2, fig. 1, p. 272, about 45 minutes before low water at Dublin Bar. The point referred to will be found marked on the map which accompanies the table. The surface water sample shows a loss of 56·8 per cent. of the saturation volume of oxygen, after having been kept for 11 days out of contact with the air.

The more highly polluted condition of the shallow water on the south side of the deep water channel during low neap tides is no doubt due to the current of ebbing water from the Clontarf strand, which causes a deflection of the polluted surface water of the channel on to the shallow water referred to.

(c) *Average Tide.*

The analyses recorded in the next Table, 10, indicate the condition of the estuary waters during the last two hours of the ebb average tide, in dry weather and with a very light west wind. The results confirm those of the preceding tables, and with them prove that the combined polluting effect of the sewages from Dublin and from the Rathmines and Pembroke townships upon the estuary waters abreast and below the Pigeon House Harbour is well within the standard of impurity which has been suggested for second class tidal waters, at all stages of the tide and at all tidal seasons, during calm and dry weather.*

On comparing the analysis of Sample 10 with that of Sample 10 in Table 8, the difference in composition of the surface water abreast of the Pigeon House Harbour during low water of different tidal seasons can be seen. Both samples were collected in calm dry weather at 4 p.m. and at 5.26 p.m., respectively. The former sample contained a smaller proportion ofriver water. The ratio of river to sea water was 1 : 2 as compared with 3 : 1 for the latter sample (compare also Sample 14, Table 9).

It may also be seen from this table that there is no tendency of the polluting matters to accumulate on the south side of the deep water channel during a low average tide in calm weather. This is no doubt due to the fact that the ebb tide runs more strongly from the south side at average tides than at neap tides (compare Samples 8 and 9, Table 10, with Samples 1, 2, 11 and 12, Table 9).

TABLE 10. ANALYSES OF SAMPLES OF ESTUARY WATER COLLECTED DURING THE LAST TWO HOURS OF THE EBB (AVERAGE TIDE), FEBRUARY 12, 1900.

High water 10.3 *a.m. Weather dry and frosty; very light West wind. Strong N.-E. winds and rain two days previously.*

No.	SURFACE SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
							Nitrogen as					Solids in suspension.	
			Carbon Dioxide.	Oxygen.	Degree of Pollution.†	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solids in solution.	Inorganic.	Organic.
		hrs.											
1	Over Outfall, at 2.52 p.m. Decidedly turbid - -	23	83·98	2·16	71·78	15·31	·440	·560	·910	999	1,986	2·940	6·410
2	200 yards below Outfall, in path of sewage, at 2.56 p.m. - - - -	48	62·74	3·80	46·68	14·26	·160	·120	·310	1,453	2,814	·634	·926
3	About 300 yards below Outfall and in path of sewage, 3.2 p.m. Distinctly turbid -	25	56·98	5·74	19·94	14·34	·125	·030	·185	1,610	3,109	·615	·885

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* See Section 1, p. 91.

† See footnote, Table 5.

TABLE 10.—Analyses of Samples of Estuary Water collected during the Last Two Hours of the Ebb (Average Tide), February 12th, 1900.—*continued.*

No.	SURFACE SAMPLES: Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N. T. P. per 1000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
			Carbon Dioxide.	Oxygen.	Degree of pollution.*	Nitrogen.	Nitrogen as			Chlorine.	Solids in solution.	Solids in suspension.	
							Ammonia.	Nitrates.	Organic.			In-organic.	Organic.
		hrs.											
4	About 300 yards below Outfall, in mid-channel, at 3.6 p.m. Faintly turbid - -	71	54·65	6·13	13·33	14·13	·020	·020	·044	1,540	2,928	Traces.	
5	Near Bull Lighthouse and within the harbour, at 3.15 p.m. Faintly turbid.	72	51·97	6·27	9·91	13·93	·010	·018	·036	1,680	3,290	Traces.	
6	Mid-channel, between Lighthouses, at 3.19 p.m. Faintly turbid - - -	96	51·68	6·23	8·88	13·67	·008	·022	·030	1,705	3,354	Traces.	
7	Near Poolbeg Lighthouse and within the Harbour, at 3.23 p.m. Faintly turbid - -	97	50·94	6·45	5·15	13·59	·005	·022	·036	1,740	3,359	Traces.	
		dys.											
8	About mid-way between the S. wall and the Lightbuoy 1, at 3.35 p.m. Quite clear.	11	51·94	5·85	13·84	13·58	·003	·022	·028	1,726	3,336	Traces.	
9	About 150 yards to the N.E. of the Outfall, at 3.40 p.m. Quite clear.	11	55·78	4·84	22·96	13·83	·030	·037	·056	1,610	3,088	Traces.	
10	Above Outfall, mid-channel, opposite the Pigeon House Fort, at 4.2 p.m. Quite clear - -	11	67·22	0·69	90·66	14·79	·048	·051	·082	1,260	2,387	Traces.	

* See footnote, Table 5.

CONDITION OF SURFACE WATERS OF THE ESTUARY IN WET WEATHER.

Table 11 contains analyses of a series of samples which were collected during the fifth hour of the ebb of a neap tide in calm but very wet weather. On comparing them with those in Tables 8 and 9 it will be found that wet weather exercises a marked influence on the surface waters of the estuary in increasing the quantities of ammonia, nitrates, organic nitrogen and carbon dioxide, as well as raising the ratio of fresh to sea water therein. Sample No. 3, which was collected from a portion of the estuary surface more particularly affected by a fresh water current, strikingly shows this influence. (Compare also Sample No. 6 with the sample of the same number in Table 10.)

With heavy rains the sewage from the townships outfall also becomes charged with fine clay and sand which impart a yellow muddy appearance to the waters of the estuary along their path (see Sample No. 1).

TABLE 11.—ANALYSES OF SAMPLES OF ESTUARY WATER COLLECTED DURING THE FIFTH HOUR OF THE EBB (NEAP TIDE), JANUARY 11, 1900.

High Water 7.7 a.m. Weather very wet; the air quite calm and foggy.

No.	SURFACE SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.					
							Nitrogen as				Solids in	
			Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solution.	Suspension.
	Sewage (Table 4, No. 3) - -	5 hrs.	127·60	4·02	0·00	16·21	1·100	·605	·350	140	343	34·0
1	Over Outfall, at 11.30 a.m. Very turbid from clayey matters in suspension. Odourless -	4 „	87·40	4·77	37·22	15·20	·600	·490	·180	665	1,332	14·2
2	100 yards above Outfall, near buoy 2, at 11.35 a.m. Distinctly turbid. Odourless. Traces of fibrous matters in suspension -	23 „	58·27	6·36	9·79	14·10	·016	·055	·054	1,313	2,710	Traces.
3	300 yards below Outfall, at 11.38 a.m., near channel and to north of path of sewage. Distinctly turbid. Traces of fibrous matters in suspension - - -	24 „	66·93	6·72	13·07	15·46	·022	·096	·060	669	1,406	Traces.
4	About 300 yards below the Outfall, nearer to path of sewage, at 11.40 a.m. Distinctly turbid. Odourless. Traces of granular matter in suspension -	27 „	60·93	6·38	14·02	14·84	·020	·070	·050	1,124	2,209	Traces.
5	Below Outfall, between the Lighthouses, nearer to path of sewage. Slightly turbid. Odourless, at 11.47 a.m. - -	46 „	60·41	6·31	12·07	14·50	·022	·073	·054	1,173	2,350	Traces.
6	At mouth, midway between the Lighthouses, at 11.50 a.m., where tide was running strongest. Similar in appearance to sample 79 -	48 „	61·04	6·34	12·55	14·70	·015	·090	·061	1,124	2,236	Traces.
7	Midway between the outfall and the Lighthouses, at 12.10 p.m. Distinctly turbid. Traces of fine granular matter in supension -	29 „	61·21	6·09	15·53	14·42	·035	·070	·065	1,173	2,346	Traces.

* *See* footnote, Table 5.

Condition of the Estuary Waters during Westerly Gales.

The two analyses recorded in Table 12 are instructive as illustrating the influence of high winds in effecting a much more thorough mixture of polluted river water with the tidal water of the estuary than that which occurs in calm weather. Both samples were collected in a westerly gale which had been blowing for the preceding twenty-four hours, and they were kept for twenty-eight days out of contact with the air, with the result that they were completely fermented before analysis. The analysis of Sample No. 2 from the channel shows that notwithstanding the fact that it was collected at low water at noon (when both the volume and foulness of the Dublin sewage might be taken at their maximum), with the wind blowing from the west, that is from Dublin and down the channel, it only lost 11·63 per cent. of the oxygen saturation volume after twenty-eight days' keeping, and that it consisted of a mixture of one part river water to fifteen parts of sea water.

Among the calm weather samples which have been recorded, perhaps that most comparable with this sample is Sample No. 3, Table 8. This sample showed a loss of 39·28 per cent. of the oxygen saturation volume, after having been kept for four days, the ratio of river to sea water being as 1 : 1. Sample No. 1 was collected from the surface of the shallow water between the south wall and buoy No. 2. The calm weather bottom and surface Samples Nos. 14 and 15, Table 7, were also collected from about the same spot, but they are not quite comparable with it since they were collected about forty-five minutes before low water, whereas the stormy weather sample was collected at low water. But even with this difference in favour of the former sample, the analyses show how comparatively restricted on the one hand is the mixture of the polluted river water with the tidal water in calm weather, and how much more general on the other hand is their mixture in stormy weather. The calm weather sample No. 15 is shown by the analysis to have been a mixture of one part of polluted river water with three parts of tidal water, and the bottom sample No. 14 a mixture of one part of the former with four parts of the latter, while the stormy weather sample was a mixture of one part of polluted river water with fifteen parts of tidal water.

Table 12.—Analyses of Samples of Estuary Water collected at Low Water (Neap Tide), January 26th, 1900.

Weather showery; very high West Wind. High tide 6.6 a.m.

No.	Surface Samples. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.					
							Nitrogen as				Solids in	
			Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solution.	Suspension.
		Days.										
1†	Above Outfall, midway between the S. Wall and the buoy 2, at 12.7 p.m. - - -	28	49·66	4·86	29·51	13·79	·001	·020	·024	1,743	3,422	traces.
2†	Above Outfall, near buoy 2, in mid-channel, at 12.18 p.m. - - -	28	49·60	5·81	11·63	13·15	·001	·013	·012	1,747	3,419	traces.

* See footnote, Table 5. † Both samples were clear and free from turbidity when analysed.

Condition of the Water of the River and Estuary in 1904 and 1905.

A second examination of the estuary was made by the same author during the month of July, 1904, and in this survey the waters of the tidal portion of the river were included.

This examination was specially made for this report with the courteous assistance of Mr. J. P. Griffith, M.Inst.C.E., Engineer to the Dublin Port and Docks Board, who very kindly placed a steam launch at his disposal for the purpose. One of his assistants, Mr. J. W. Griffith, M.Inst.C.E., also accompanied him and kindly rendered material assistance in selecting typical points for taking samples and in taking observations.

A third examination of the condition of the estuary waters, abreast and below the Pigeon House, was made in April, 1905. As it was confined to the estuary it will be convenient to deal with it first. The samples collected and the results of their analyses will be found in the succeeding Table 13.

Table 13.—Analyses showing the Degree of Pollution in Samples of Estuary Waters, which were collected on March 22nd, 1905, during the fifth hour of the ebb of a Neap Tide, after keeping them for twenty-one days out of contact with the air (*Adeney*).

High Water 5.34 a.m. Wind strong from the W.SW. Weather fine.

Dissolved Gases expressed in volumes at N.T.P. per 1,000 *volumes of Water.*

—	When Collected.	Carbon Dioxide.	Oxygen.	Degree of Pollution.*	Nitrogen.
1. Sewage from bottom of Penstock Chamber.	9.55 a.m.	113·9	2·2 †	—	16·5
2. Vertically over the Outfall - -	10.0 a.m.	82·4	4·8 †	35·14	14·80
3. Abreast Outfall, Mid-Channel -	10.3 a.m.	50·12	3·9	39·26	12·84
4. Abreast Outfall to north of Channel, near Beacon.	10.8 a.m.	50·6	4·7	27·88	13·0
5. Midway between Outfall and Mouth, to south of Channel.	10.25 a.m.	51·56	4·4	34·00	13·16
6. Ditto, Mid-Channel - - -	10.28 a.m.	50·97	4·0	37·70	12·84
7. Ditto, to north of Channel - -	10.33 a.m.	52·02	4·53	30·71	13·08
8. Immediately above Poolbeg Light, to south of Channel.	10.43 a.m.	49·97	4·53	29·55	12·68
9. Ditto, Mid-Channel - - -	10.46 a.m.	49·46	4·41	31·57	12·89
10. Immediately above Bull Light, to north of Channel.	10.49 a.m.	51·60	4·05	36·32	12·72

All the samples of Estuary Water contained minute traces of finely divided matters in suspension.

* *See* footnote, Table 5.

† These samples were analysed within six hours after collection.

The weather conditions were such as to give rise to a maximum polluting effect by the sewage both from Dublin and from the townships upon the waters of the lower portion of the estuary. It was dry, and a strong wind was blowing diagonally across the estuary from the W.SW.; the samples, moreover, were collected in the morning when the sewages were probably at their maximum strength and volume.

On reference to the results of analysis it will be found that the samples, with the exception of the one which was collected directly over the outfall and which was analysed without delay, were all kept 21 days out of contact with the air before they were examined. The maximum polluting effect by the Dublin sewage is shown by Sample 3 which was collected from the surface of the deep water channel abreast of the townships outfall. The de-aeration caused by pollution in this sample amounted to 39·3 per cent. of the oxygen saturation volume. The de-aeration of the corresponding Sample 4 which was collected to the north of the channel, and abreast of the outfall, was distinctly less, viz., 27·9 per cent. of the saturation volume.

The analyses of the remaining Samples 4 and 5 illustrate the combined polluting effect of the sewages from both sources. The portion of the estuary most affected by them will be found on reference to the results to be where Sample 6 was taken, that is from the surface of the deep water channel midway between the townships outfall and the mouth of the estuary; and the portion next in order of pollution is shown by Sample 10 to be north of the channel immediately above the Bull Lighthouse. The former sample showed a pollution which caused a de-aeration amounting to 37·7 per cent., and the latter sample a de-aeration amounting to 36·3 per cent., of the oxygen saturation volume.

It is again evident from these results that the combined polluting effect of the two sewages from Dublin and from the townships would have had a scarcely appreciable effect upon the aeration of the lower estuary waters had they been examined immediately on collection, since the rate of re-aeration, as shown in the section on Chemical Changes, etc., p. 65, for a mixture of equal parts of fresh and salt water would be greater than the rate of de-aeration shown by any of these samples.

In Table 14, analytical results are given which reveal the state of aeration of the surface and bottom waters of the tidal portions of the river, as well as of the estuary, a few hours after collection on several days during the month of July, 1904, at different tidal seasons and at different states of the tide, and further under weather and wind conditions precisely opposite to those which prevailed when the first series of samples were collected in the year 1900. The weather was more or less wet, and high winds prevailed more or less from the east, that is from the direction best calculated to retain the polluted river waters within the harbour and so to bring about the maximum polluting effect by them of the tidal waters.

On reference to the results recorded in the table, it will be found that the aeration of the bottom samples from the river was found in one case only to be below 60 per cent. of the oxygen saturation volume, viz., in the case of the Sample No. 13 which was collected at the mouth of the Dodder and kept 25 hours out of contact with air before analysis. It is obvious however from the results of analysis generally of this and of other samples recorded in the same table, that the exceptionally large reduction of the aeration of this sample must have been due to the absorption of oxygen by easily oxidisable solid substances, *e.g.*, ferrous sulphide,* from the bed of the river, which, as already shown, is very foul at this point, and from which masses of black mud rise from time to time to the surface of the water and become disseminated through it. This conclusion is warranted by several considerations. The chlorine determinations prove that the sample very largely consisted of sea water, while the polluting matters were borne by fresh water. The quantity of ammonia in the sample also shows that it could not have contained more than 1 per cent. of liquid sewage of the strength of average town sewage, and the results which are given in the section just referred to† for the de-aerating effect upon fully aerated waters of different proportions of sewage show that so small a proportion of sewage is insufficient to account for such a large reduction of aeration in so short a time. The analyses moreover of other samples polluted by about similar quantities of liquid sewage matter, and recorded in the same table, indicate degrees of aeration much higher than this particular sample. (Compare Nos. 9, 10 and 17.)

Of the surface samples only five of them would be condemned by the suggested standard for second class tidal waters; they are Nos. 12, 13, 16, 22 and 28. A careful examination however of the general results of analysis of these samples leads to the conclusion that the low degree of aeration of them was largely to be ascribed to the absorption of oxygen by easily oxidisable solid matters in suspension, and not by fermentative changes of sewage organic matters in solution.

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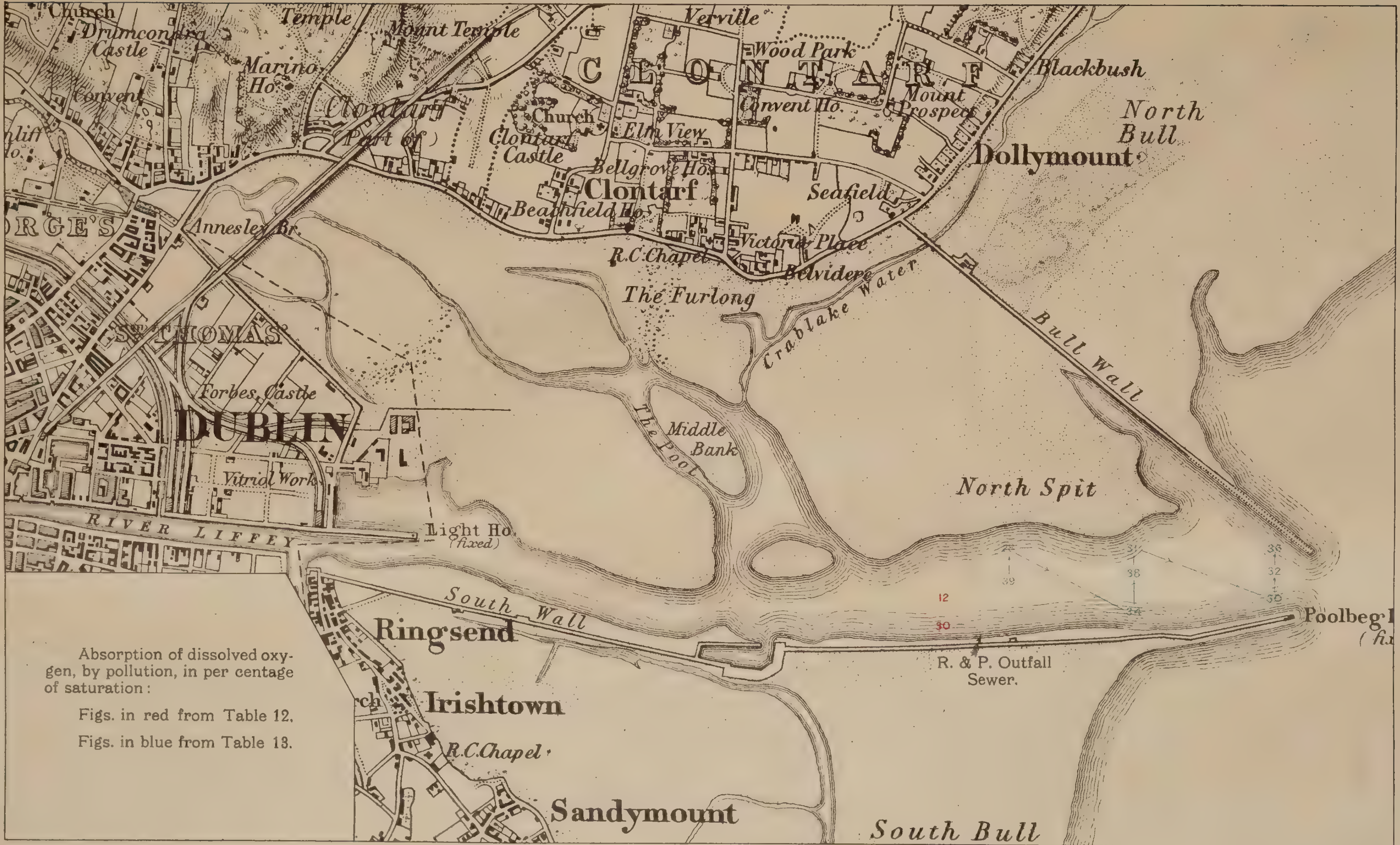
* Section on Chemical Changes, etc., p. 65. † *Ibid.*, p. 65.

F.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Map to illustrate Dr. Adeney's Section on the Liffey Estuary.



Absorption of dissolved oxygen, by pollution, in per centage of saturation:

Figs. in red from Table 12.

Figs. in blue from Table 13.

Ordnance Survey, Southampton.

TABLE 14.—ANALYSES SHOWING THE POLLUTION AND PERCENTAGE OF AERATION IN SAMPLES OF THE TIDAL AND NON-TIDAL WATERS OF THE LIFFEY, COLLECTED IN JULY AND NOVEMBER, 1904 (*Adeney*).

Gaseous Constituents expressed in Volumes at N.T.P. per 1,000 Volumes, and other Constituents in Parts by Weight per 100,000 Volumes of Water.

Number of Sample.	Date.	Description of Samples.	Temperature X. C.	When collected.	State of Tide.	Wind.	Time* kept.	Carbon Dioxide.	Oxygen.	Nitrogen.	Chlorine.	Nitrogen as Ammonia.	Oxygen in per cent. of saturation.†
				a.m.			hrs.						
1	July 12	Abreast Martin's Ferry Steps -	17·5	10.7	¼ hr. ebb	E.S.E.	5	53·75	3·04	11·50	1593	·063	53·1
2	,,	Ditto, 30 ft. below surface - -	17·9	,,	,,	,,	6	47·56	3·65	10·83	1902	·026	67·4
3	,,	Abreast Pigeon House - -	17·3	p.m. 12.0	2 ,,	,,	5	45·08	5·70	11·40	1802	·016	100·0
4	,,	Ditto, 24½ ft. below surface - -	17·0	,,	,,	,,	5	42·50	5·74	11·08	1917	·008	100·0
5	,,	Between Poolbeg and Bull Lighthouses - -	16·4	12.15	2¼ ,,	,,	5	42·24	5·80	11·35	1917	·007	100·0
6	,,	Ditto, 25 ft. below surface - -	17·3	,,	,,	,,	5	41·55	5·64	11·01	1927	·002	100·0
7	,, 14	Abreast Martin's Ferry steps -	16·4	1.25	1¾ ,,	S.E.	20	47·72	3·02	11·78	1672	·048	51·1
8	,,	Ditto, 28 ft. below surface - -	15·8	,,	,,	,,	21	43·76	4·68	11·57	1866	·02	80·9
9	,,	Abreast North Wall Light -	16·3	1.37	2 ,,	,,	22	51·64	3·16	11·58	1705	·028	54·6
10	,,	Abreast Pigeon House - -	15·0	1.45	2¼ ,,	,,	24	43·50	5·84	11·37	1902	·005	100·0
11	,,	Near new lighthouse, eastern breakwater	15·0	2.45	3¼ ,,	,,	24	46·63	4·43	11·36	1933	·006	78·0
12	,,	Off Mouth of Dodder - -	17·2	3.20	3¾ ,,	,,	24	66·67	0·26	12·77	1048	·172	4·7
13	,,	Ditto, bottom sample - -	16·0	,,	,,	,,	25	51·15	1·65	11·94	1775	·025	27·6
14	,,	Abreast Half-Moon battery - -	15·2	4.40	5 ,,	,,	25	49·11	4·99	11·30	1860	·021	85·6
15	,,	Ditto, 19 ft. below surface - -	15·4	,,	,,	,,	26	46·21	4·98	11·63	1852	·021	88·3
16	,, 20	Abreast Martin's Ferry Steps -	17·0	a.m. 10.20	L. water	E.	5	48·29	0·12	12·35	1043	·095	1·94
17	,,	Ditto, 11½ ft. below surface - -	16·0	,,	,,	,,	6	46·07	3·63	12·12	1792	·021	60·0
18	,,	Abreast Pigeon House - -	16·4	10.40	,,	,,	20	49·44	3·81	11·37	1729	·017	67·2

* The bottles in which the samples were collected were completely filled and carefully stoppered, so as to leave no air in them. The time each sample was kept is given in this column.

† The calculations in this column are based upon the assumption that the maximum quantity of oxygen which a pure water can hold in solution is one-half the nitrogen in solution.

NOTES.—July 12. The surface of the water was discoloured down to the Pigeon House; it was clear and clean at the mouth The wind was fresh. All the samples collected contained small quantities of finely divided solid matters in suspension.

,, 14. Water discoloured down to Pigeon House Harbour, clear at mouth, strong breeze. All the samples contained slight quantities of finely divided solids in suspension.

,, 20. Much rain previous day and night, estuary discoloured down to its mouth, very little solid matters in suspension.

,, 21. Water less discoloured, fairly strong wind.

,, 26. Water distinctly coloured to Pigeon House, but little below this; wind strong, sea rough, weather damp.

TABLE 14.—Analyses showing the Pollution and Percentage of Aeration in Samples of the Tidal and Non-Tidal Waters of the Liffey, collected in July and November, 1904 (*Adeney*)—*continued.*

Number of Sample.	Date.	Description of Samples.	Temperatuae X. C.	When collected.	State of Tide.	Wind.	Time* kept.	Carbon Dioxide.	Oxygen.	Nitrogen.	Chlorine.	Nitrogen as Ammonia.	Oxygen in per cent. of saturation.†
19	July 20	Abreast Pigeon House, 11¾ ft. below surface -	16·0	a.m. 10.40	L. water	E.	21	45·64	4·80	11·61	1832	·017	82·7
20	,,	Between Poolbeg and Bull Lighthouses - -	16·2	11·5	½ hr. fld	,,	22	45·70	5·67	11·35	1848	·006	99·9
21	,,	Ditto, 23½ ft. below surface - -	15·9	,,	,,	,,	23	43·71	5·86	11·59	1862	·002	100·0
22	,, 21	Abreast Technical School, Ringsend	17·9	11·30	L. water	S.	3	48·33	0·95	12·33	993	·092	15·4
23	,,	Ditto, 21½ ft. below surface - -	16·0	,,	,,	,,	4	40·22	4·05	11·48	1824	·015	70·6
24	,,	Abreast Pigeon House - -	17·2	11·45	,,	,,	5	45·13	4·34	11·27	1714	·024	77·0
25	,,	Ditto, 18 ft. below surface - -	16·6	,,	,,	,,	6	42·72	4·97	11·57	1834	·011	86·0
26	,,	Between Poolbeg and Bull Lights	16·2	12·5	⅓ hr. fld	,,	20	42·45	5·03	11·39	1845	·015	88·1
27	,,	Ditto, 22 ft. below surface - -	15·8	,,	,,	,,	21	42·35	5·66	11·32	1891	·002	100·0
28	,, 26	Abreast Martin's Ferry Steps -	16·6	10·45	½ hr. ebb	N.E.	3	60·53	2·36	12·46	1262	·06	37·9
29	,,	Ditto, 30 ft. below surface - -	15·8	,,	,,	,,	4	47·85	4·47	11·59	1813	·023	77·0
30	,,	Abreast of Pigeon House - -	15·8	11·3	¾ ,,	,,	5	48·03	4·54	11·51	1790	·023	79·0
31	,,	Ditto, 30 ft. below surface - -	15·0	,,	,,	,,	6	43·98	5·86	11·53	1935	·007	100·0
32	,,	Between Poolbeg and Bull Lights -	14·5	11·25	1 ,,	,,	20	43·66	5·58	11·37	1949	·001	98·4
33	,,	Ditto, 31 ft. below surface - -	15·0	,,	,,	,,	21	44·42	5·77	11·36	1935	·002	100·0
34	,,	Non-tidal water just above weir, heavy rain overnight succeeding dry weather -	11·0	—	—	—	2	79·77	6·73	15·36	—	·01	87·64

* The bottles in which the samples were collected were completely filled and carefully stoppered, so as to leave no air in them. The time each sample was kept is given in this column.

† The calculations in this column are based upon the assumption that the maximum quantity of oxygen which a pure water can hold in solution is one-half the nitrogen in solution.

NOTES.—July 12. The surface of the water was discoloured down to the Pigeon House, it was clear and clean at the mouth. The wind was fresh. All the samples collected contained small quantities of finely divided solid matters in suspension.

,, 14. Water discoloured down to Pigeon House Harbour, clear at mouth, strong breeze. All the samples contained slight quantities of finely divided solids in suspension.

,, 20. Much rain previous day and night, estuary discoloured down to its mouth, very little solid matters in suspension.

,, 21. Water less discoloured, fairly strong wind.

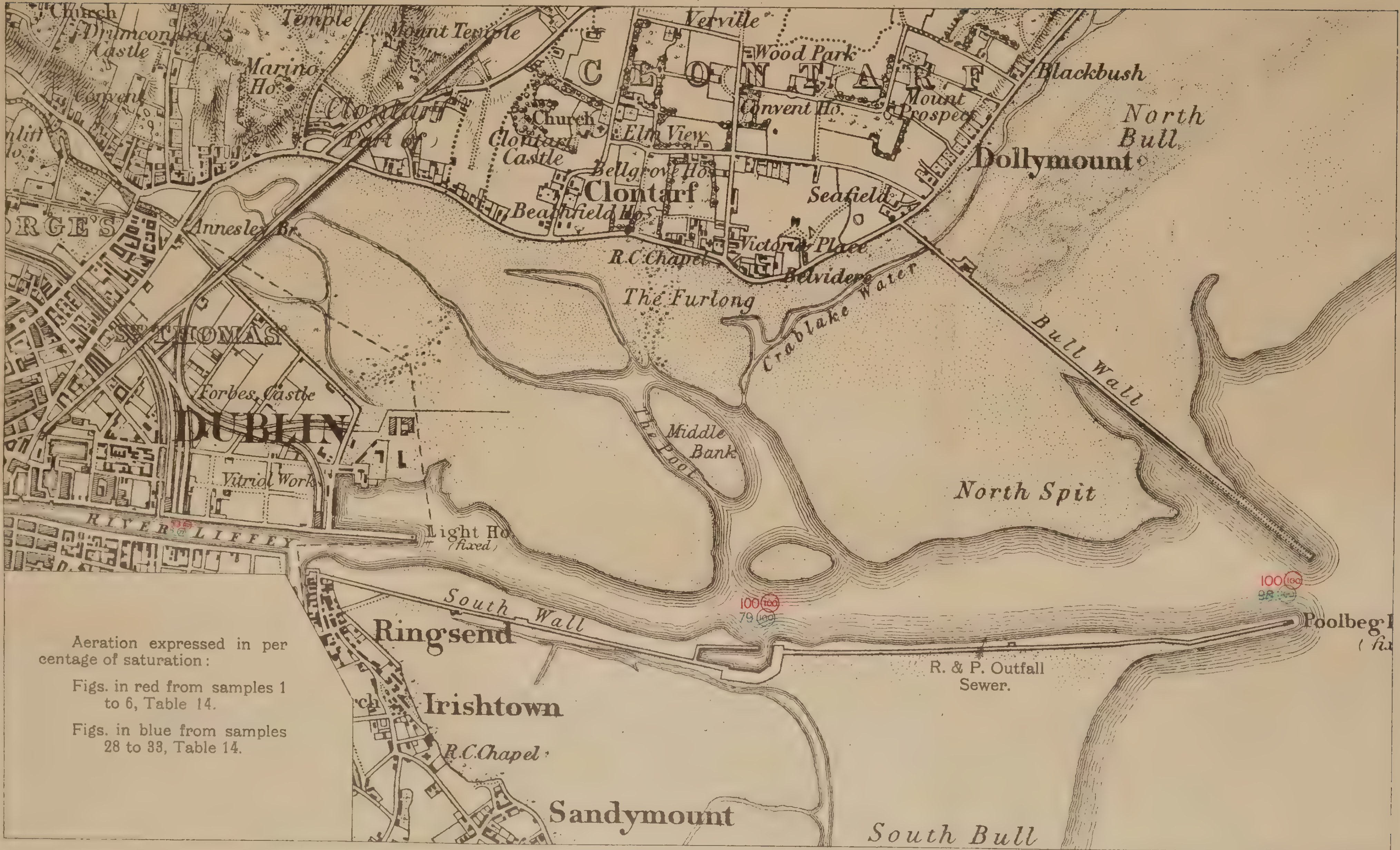
,, 26. Water distinctly coloured to Pigeon House, but little below this, wind strong, sea rough, weather damp.

It is quite evident from the chemical composition of the bottom waters of the river and estuary, and from their freedom from serious pollution, that they must be practically renewed by fresh and unpolluted sea water at every flood and ebb tide period. It will be observed, on comparing the analyses in Table 14 with those obtained during the first survey in 1900, that there is no tendency whatever for polluting matters to accumulate in the estuary waters.

G.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Map to illustrate Dr. Adeney's Section on the Liffey Estuary.



Aeration expressed in per centage of saturation:

Figs. in red from samples 1 to 6, Table 14.

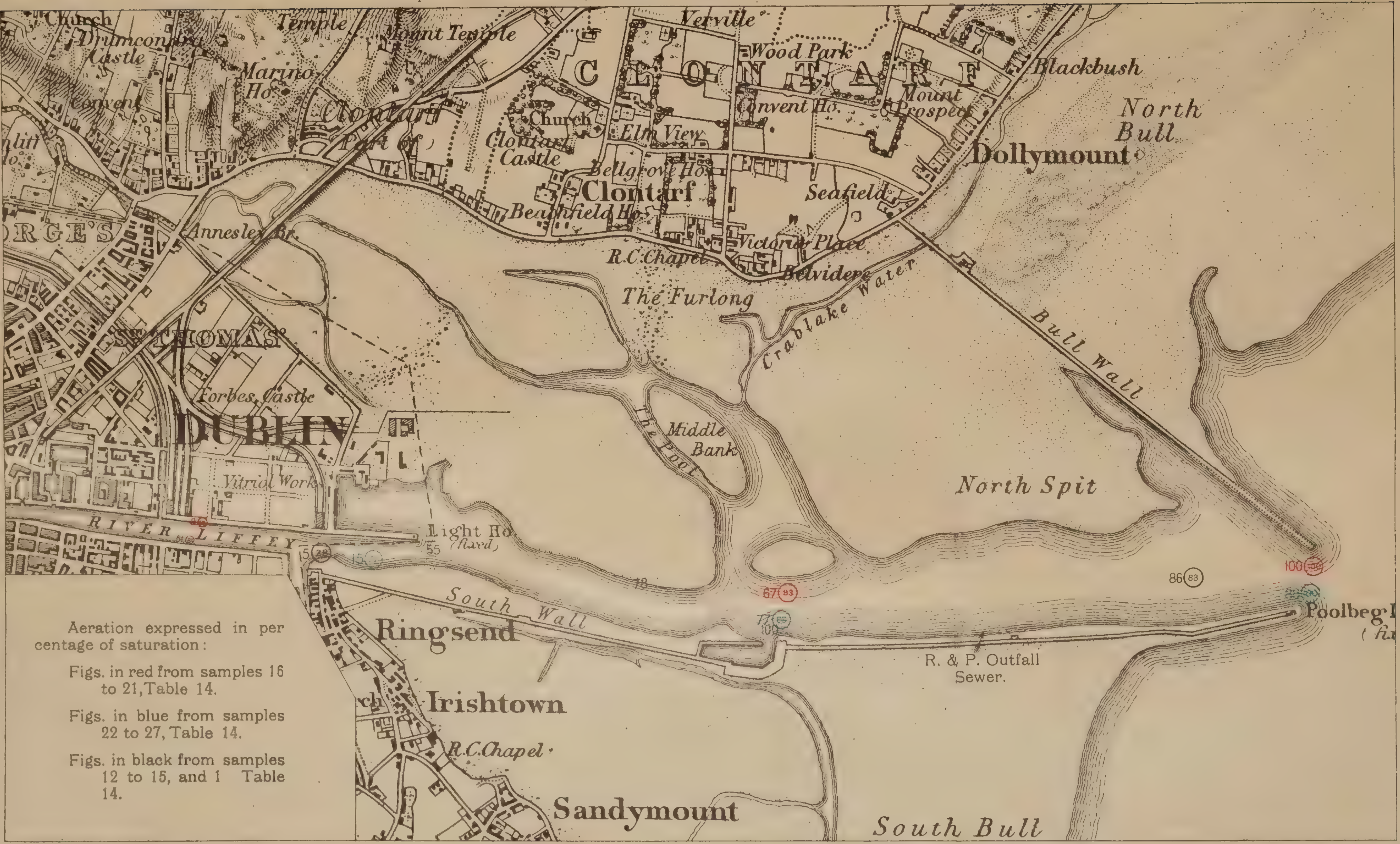
Figs. in blue from samples 28 to 33, Table 14.

Ordnance Survey, Southampton.

H.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

Map to illustrate Dr. Adeney's Section on the Liffey Estuary.



Aeration expressed in per centage of saturation:

Figs. in red from samples 16 to 21, Table 14.

Figs. in blue from samples 22 to 27, Table 14.

Figs. in black from samples 12 to 15, and 1 Table 14.

Ordnance Survey, Southampton

This fact explains two observations which have frequently been noticed with surprise by local observers viz., (1) salmon freely pass up the river on their way to its upper and non-tidal reaches, notwithstanding the polluted condition of its bed and surface waters; and (2) no specific disease has been observed amongst the densely populated quarters of the city lying on both banks of the river which has been attributable to the polluted condition of the bed.

The first mentioned fact is one of common observation by local fishermen and watermen. One of the authors (Adeney) noticed on July 12th, 1904, three dead salmon lying on the surface of the river, but the death of these fish was evidently caused by chloride of lime which was present at the time in the surface of the waters in sufficient quantity to impart to them a white muddy appearance. This was, however, an exceptional state of things.

The second statement is made on the authority of the distinguished Medical Officer of Health for Dublin, Sir C. A. Cameron, C.B., M.D. The fact that the polluted bed of the river does not give rise to any specific sickness amongst the surrounding population is no doubt due to the fact that it is washed at every flood tide by clean and fully aerated sea water, which effects the oxidation of offensive organic products of anaerobic fermentation. That this form of fermentation does occur in the polluted mud overlying the bed of the river is sufficiently proved by the presence in it of ferrous sulphide, which has already been noticed, and the direct oxidation of it and of other easily-oxidisable products of anaerobic fermentation explains the excessive absorption of dissolved oxygen, which has also already been noticed, and which otherwise it is impossible to account for.

There can be little doubt therefore that if the solid matters of the Dublin sewage had been removed before it was discharged from the existing outfalls into the river, the bed of the latter would not have been fouled, and the aeration of the river water would not have been reduced below the allowable limit laid down by the suggested standard.

Two considerations, however, arise to minimise the consequence of this conclusion. They are: (1) the discoloration of the river water by the sewage which would still be produced if the solids only were removed from it without further purification, and (2) the probability that if the bed of the river and estuary were unpolluted by solid sewage matters, the growth of the ulva latissima along the same would be encouraged, and so in the end the nuisance would be reproduced in another form.

It would, therefore, be necessary either to cease to discharge sewage matters of any kind into the river or upper reaches of the estuary, or to thoroughly purify the sewage before discharge into the river.

The former alternative was adopted by the Corporation of Dublin some years ago, and at the time of writing the new main drainage system of Dublin is being put into operation by which the sewage is brought down to the Pigeon House, where precipitation tanks and outfall works have been constructed on the site of the old harbour. The solids are to be precipitated by the addition of four grains of lime per gallon, and the effluent is to be discharged into the deep water channel abreast of the old harbour, at all states of the tide.

It is a matter for regret that the effluent is to be discharged on the flood tide as well as on the ebb, as there can be little doubt from the very careful examinations which have been made of both the bed and waters of the river and estuary, and which have been described in the foregoing pages, that the separation of the solids would be sufficiently effected by mechanical subsidence and fine mesh screens, provided that the subsequent discharge of the liquid sewage matters from the new outfall works was restricted to the first four or five hours of the ebb tide.[*]

It is to be feared that unless the sewage be much more efficiently clarified than is possible by the proposed treatment with four grains of lime per gallon, the result of discharge at all states of the tide will be to discolour the surface waters of the estuary and river and to set up more favourable conditions for the growth of the *ulva latissima* on the bed of the estuary (and even on that of the river) than has up to the present existed.

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[*] The new sewerage works at Frankfort-on-Main show that, with well-designed catch-pit rotary screens and subsidence tanks, 16 per cent. of the suspended solids are removed by the catch-pit, 10 per cent. by the screens and 64 per cent. by the subsidence tanks. Total 90 per cent.

The use of lime also if not carefully employed may not be unattended with danger to fish life.

It will soon, however, be possible to judge from actual results whether these anticipated fears are groundless or not. Meanwhile there can be no doubt that the new works will very greatly improve the present condition of the river, and if experience results in showing that the discharge should be limited to the ebb tide as above suggested in the interests of all concerned, it will no doubt be possible for the Corporation to provide for such discharge.

Summary and Conclusions.

(1) The estuary comes under the second of the three classes into which tidal waters may be divided for the purpose of sewage disposal, and which includes those waters whose ebb currents can transport the *liquid* sewage matters discharged into them, and widely distribute them in open water in directions which preclude the possibility of their being carried back in appreciable quantities by the ensuing flood tide.

(2) If the whole of the liquid sewage matters of Dublin were discharged into the river from the existing outfalls along the quay walls, as at present, with the exception that the suspended solids were previously removed, the aeration of the waters of the river and estuary would not be reduced by them below the limit allowed by the standard formulated for this class of waters in the section on Chemical Changes, etc., p. 91.

The surface of the waters would, however, continue to be discoloured, and it would be obviously undesirable to continue the discharge of such large volumes of unpurified liquid sewage matters into a narrow tidal river like the Liffey, and so near to the City.

The new Main Drainage Outfall Works which have just been erected and put into operation by the Corporation of Dublin on the site of the old Pigeon House Harbour are designed to prevent the direct discharge of sewage into the river, but to carry it down to the deep water channel of the estuary, and to discharge it after precipitation of solids by treatment with lime, within two miles of the mouth of the same at all states of the tide.

(3) The discharge of sewage from the Rathmines and Pembroke outfall is legally limited to the first five hours of the ebb, and the point of discharge is only one mile above the mouth of the estuary and is far removed from dwelling houses. The sewage produces a discolouration of the surface of the estuary waters along its path, especially in calm wet weather, but the path is very narrow relatively to the width of the estuary, and is not sufficient in the opinion of the authors to warrant it being regarded as a nuisance or as a danger to public health or to fish life, having regard to the position and neighbourhood of the part of the estuary affected by it. The de-aerating effect of the sewage from this outfall upon the estuary waters in its path is scarcely appreciable even at the lower states of the ebb tide.

But the light suspended solid matters which are discharged with the liquid sewage temporarily accumulate, with prevailing northerly winds, along the south wall during low water, and such accumulations are offensive to look at. The floating portions moreover of the light solids referred to, such as corks, are blown about the waters of the estuary and give a bad appearance wherever they accumulate, which they do along the shores of the estuary when in-shore winds prevail for lengthened periods.

In the opinion of the authors, the light solids above referred to ought to be removed before the liquid sewage is discharged from the outfall, and the authors believe that they could be sufficiently removed by means of revolving fine mesh wire screens.

(4) During calm weather the surface waters of the river and estuary alone are affected by the sewage discharged into them. The bottom waters of the less shallow portions of the estuary remain practically unpolluted where the bed of the channel is itself not fouled by the deposit of solid sewage matters upon it.

Sewage solid matters, when discharged into a second class tidal water in appreciable quantities, exercise a highly polluting effect both on its bed and on its waters, and must be removed before the discharge of the sewage.

In the case of second class tidal waters with such favourable tidal currents and of such large volume as those of the Liffey, the removal of the solids may, in all probability, be sufficiently effected by mechanical subsidence and screening through fine mesh wire screens, provided that the discharge of the liquid sewage is limited to the first four or five hours of the ebb tide.

(6) Under the conditions which obtain with the discharge of the sewage from the Rathmines and Pembroke outfall, the sewage in calm weather rapidly becomes diluted with from eight to ten times its volume of estuary water, but that further dilution and dispersion proceeds very slowly except in windy weather. It should be noted that the invert of this outfall is situated at such a depth that at low water of equinoctial springs it is covered by about five feet of water, and that, during the periods of discharge of sewage from it, it is covered by from eight to eighteen feet of water. The outfall is therefore a deep water one and discharges into the deep water channel.

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Royal University, Dublin.

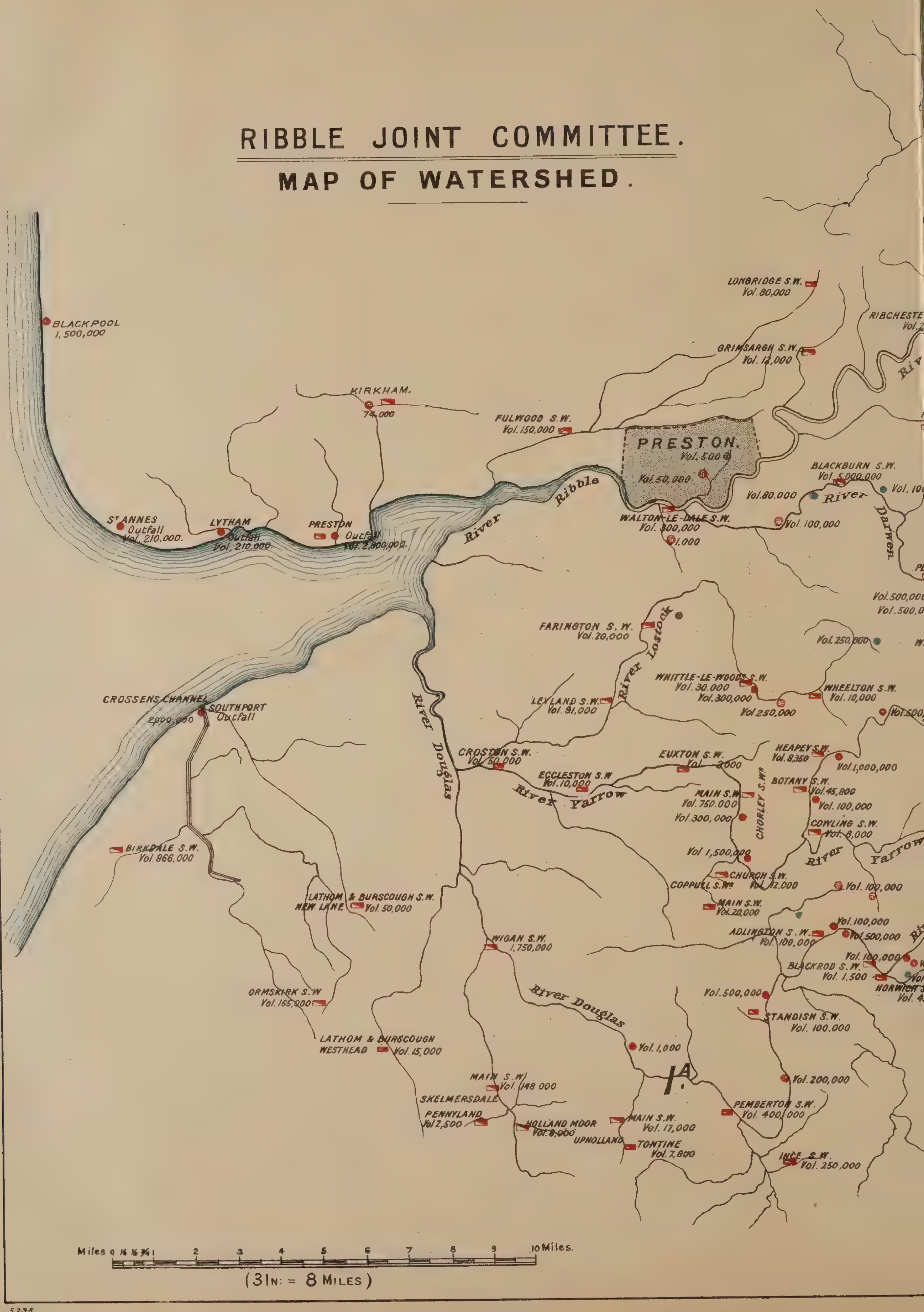
SECTION 7c.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

PRESTON AND THE RIBBLE ESTUARY.

RIBBLE JOINT COMMITTEE.

MAP OF WATERSHED.



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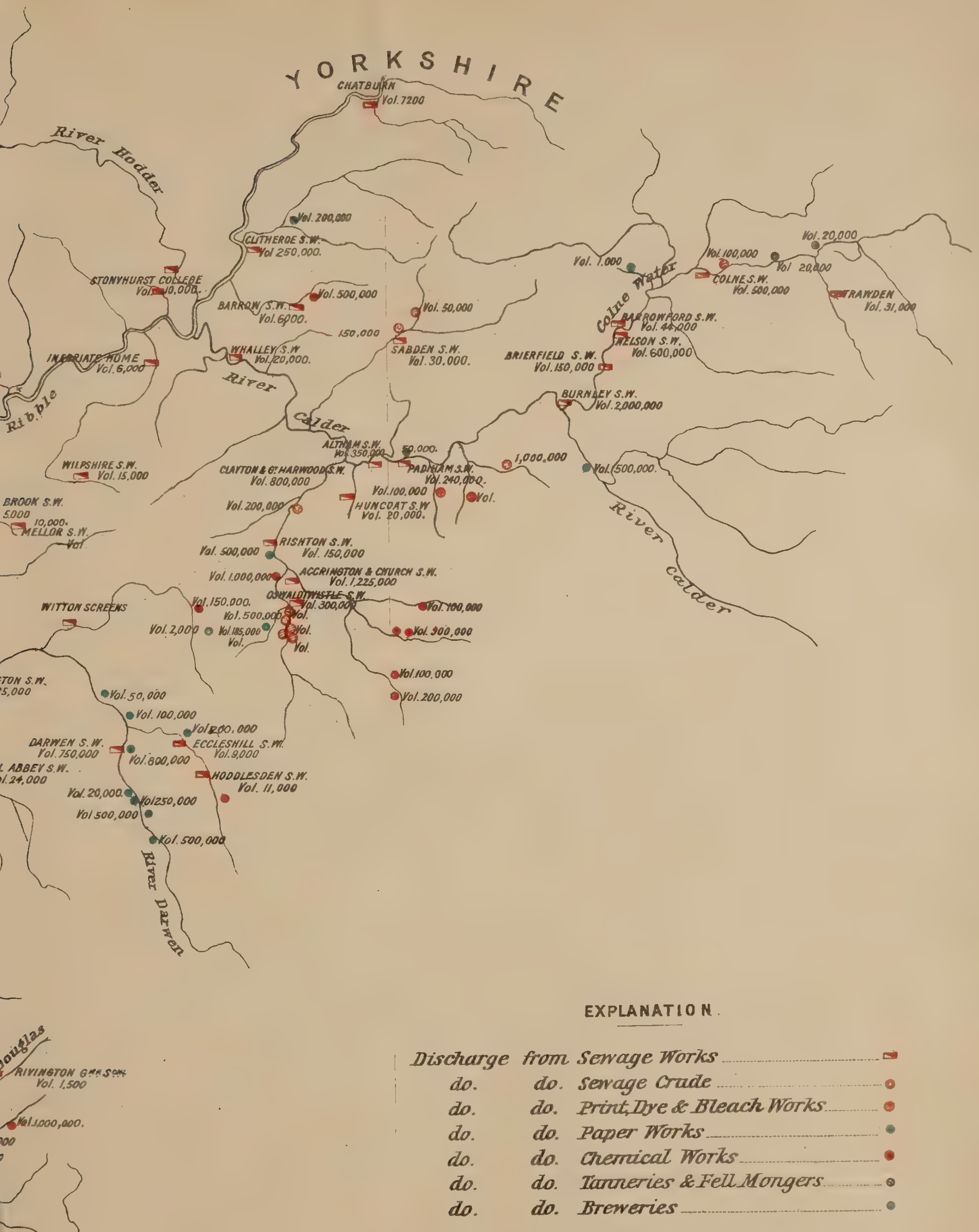

EXPLANATION.

Discharge	from	Sewage Works	▬
do.	do.	Sewage Crude	○
do.	do.	Print, Dye & Bleach Works	●
do.	do.	Paper Works	●
do.	do.	Chemical Works	●
do.	do.	Tanneries & Fell Mongers	⊙
do.	do.	Breweries	●

Note. All Figures are normal dry weather Flow in gallons per 24 hours.

[The Blue shading in the rivers marks their tidal limits.]

EDWARD HALLIWELL F.I.C.
Chief Inspector,
PRESTON.

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PRESTON AND THE RIBBLE ESTUARY.

The watershed of the Ribble embraces a district having an area of about 566 square miles, with a population of 1,222,000. The total length of the rivers included in the watershed, namely the Ribble and its tributaries the Calder, Hodder and Darwen, together with the Douglas, which opens into the Estuary of the Ribble, and the feeders of these streams, amounting to about 180 miles.*

The Ribble rises in Yorkshire, but in its progress through that county receives no pollution to speak of. Passing into Lancashire it unites with the Hodder, and about a mile lower down, at Mitton, receives the waters of the Calder, a tributary of considerable size, and one which is extensively polluted both with sewage and manufacturing effluents. No further extensive pollution occurs in the main stream during its flow to Preston (a distance of 18 miles from Mitton), but at that town the Darwen flows into it, a tributary which like the Calder is heavily polluted.

At Preston (near its junction with the Darwen), the Ribble becomes a tidal stream, and after a flow of a couple of miles or so, gradually broadens out into the estuary. Some six miles below Preston, and when the estuary has widened out considerably, the Douglas, or Asland, joins it, a river which like both the Calder and Darwen is highly polluted, both with sewage and trade effluents.

The sewage of Preston is discharged (after land treatment) into the estuary at a point situated about 8 miles from the town, and it will be seen from the map of the watershed, that the Ribble itself does not receive any serious pollution, the fouling of its waters above the tidal limit being caused almost entirely by its tributaries the Calder and Darwen, while below that limit additional pollution is thrown in by the Douglas.

As regards these three rivers:—

The Calder and its feeders, the Pendle Water and the Hyndburn, receive the sewage effluents of two towns of considerable size, namely Burnley and Accrington, and also those of some fourteen other towns, of which the most important are Colne, Nelson, Padiham, Altham, Oswaldtwistle, Clayton and Great Harwood. The total volume of sewage effluents thus introduced into the Calder amounts to between 6 and 7 million gallons (normal dry weather flow per 24 hours), while in addition, the manufacturers' effluents are estimated as amounting to nearly 5 million gallons: these being derived from numerous and varied industries, such as paper-making, print, dye and chemical works, breweries, tar distilleries, etc.

The Darwen, like the Calder, runs through a thickly populated industrial district, and is therefore also heavily polluted with both sewage and trade effluents.

But there are important differences between these two tributaries of the Ribble. In the first place the dry weather flow of the Darwen is roughly only half that of the Calder, while the total volume of sewage and trade effluents which it receives is not very different from that discharged into the Calder. Also, whereas the pollution of the latter river by sewage effluents is distributed over a fairly wide area and consists of contributions from a relatively large number of towns, the sewage pollution of the Darwen originates chiefly from one town only, namely, Blackburn, which contributes about 85 per cent. of the total, the only other place of any importance in the valley of this river being the town of Darwen, which contributes about 13 per cent., the remainder being derived from five small sewage works.

It should also be noted that the sewage works of Blackburn are distant about four miles only from Preston, so that but little time is given for any processes of self-purification to occur in the sewage effluent of that town before it passes into the Ribble.

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* Evidence of Mr. Alderman Jonathan Phillips, vice chairman of the Ribble Joint Board. Roy. Com. on Salmon Fisheries Rep. Part 2, p. 660.

[In the First Report of the Rivers Pollution Commission (1868) the area is given as 816 square miles and the population in 1861 as 489,176.]

As to the trade effluents entering the Darwen, their volume is estimated at nearly 4 million gallons (normal dry weather flow per 24 hours), contributed by about sixteen different establishments, of which twelve are paper works.

The Douglas, with its tributaries, the Lostock and Yarrow, also pass through a thickly populated manufacturing district, the chief towns situated in its watershed being Wigan and Chorley. The total volume of sewage effluents discharged into the Douglas and its tributaries is estimated at about 4⅓ million gallons (normal dry weather flow per 24 hours), of which Wigan contributes about 40 per cent. and Chorley nearly 20. The remainder is received from a considerable number of smaller localities of which Horwich, Adlington, Standish, Ince and Skelmersdale are among the more important.

The trade effluents thrown into the Douglas and its tributaries are estimated as amounting to about 7 million gallons (normal dry weather flow per 24 hours), contributed by some nineteen different establishments, of which fourteen are print, dye, or bleach works.

The Douglas becomes tidal near Croston, which is situated some eight miles above the junction of the river with the estuary of the Ribble. In its lower tidal reaches the stream is artificially controlled by the Hesketh embankment.

It should be mentioned that some of the water of this river (and in dry weather practically the whole volume) is diverted below Wigan (at a point marked 1A on the map) to the Leeds and Liverpool Canal.

Speaking generally, the rivers of the Ribble watershed lie in somewhat narrow valleys, the land on either side of which is fairly high, and, as a consequence, they are quickly affected by a rainfall.

Another feature also deserves notice. The rivers are often diverted for manufacturing purposes by "goits" or intakes into "lodges," and in dry weather these lodges frequently receive all the available water, the natural bed of the stream being practically dry. The lodge then forms a settling tank which no doubt acts beneficially to the general condition of the water, for the time being until the accumulation of deposited solids is cleared out, either naturally by a flood or artifically by removing or altering the weirs. In either of which cases pollution, possibly of a devastating kind in relation to fish life, may be suddenly thrown into the stream.

The condition of the rivers constituting the greater part of the Ribble watershed is controlled by the Ribble Joint Committee—a body constituted in 1891.*

Previous to that date, the different local authorities were for the greater part discharging the sewage of their respective districts into the rivers without treatment, and the manufacturers also were discharging their waste products into them without restriction.

The first step taken by the Committee was to serve notice upon all the authorities that the sewage must be treated before it was turned into the rivers, and a similar notice was served upon all manufacturers with regard to their effluents.

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* The Local Government Board's Provisional Orders Confirmation (No. 10) Act, 1891 thus defines the scope and powers of the Joint Committee :—

Art. II.—(1.) A Joint Committee (herein-after referred to as "the Joint Committee") shall be constituted for the purpose of enforcing the provisions of the Rivers Pollution Prevention Act, 1876 (subject to the provisions in that Act contained), in relation to so much of the River Ribble, or any tributary thereof, and of the Rivers Darwen and Douglas, and the streams (as defined by the said Act of 1876) running into the Crossens Channel, as passes through the County of Lancaster, or through or by the County Boroughs of Blackburn, Burnley, Preston, and Wigan :

Provided that the appointment of the Joint Committee shall not prejudice or in any way affect or curtail the right of any Sanitary Authority represented upon the said Committee to continue proceedings already taken, or to commence proceedings, against any person or persons in respect of any pollution of the River Ribble, or any tributary thereof, or of the River Darwen, or of the River Douglas, or of the streams (as defined by the said Act of 1876) running into the Crossens Channel.

(2.) The Joint Committee shall consist of sixteen members, representing the said County and County Boroughs, and shall be a body corporate by the name of the Joint Committee of the River Ribble, with perpetual succession and a common seal, and with power to sue and be sued in that name.

Many difficulties were encountered by the several authorities at first in conforming to this order: one of the most serious of which was that the Local Government Board would not at that time sanction the borrowing of money for any scheme unless such scheme included land upon which the effluent resulting from a preliminary process of chemical precipitation or filtration could be further treated, and in certain cases (*e.g.*, Church and Accrington) no suitable land for the purpose was available.

The consequence of this was that while a fairly good effluent could be obtained without the use of land, only a fraction of the sewage could be treated, as the payment for the extensions had to come out of the revenue, and the construction of works for treating the whole of the sewage of a given district was seriously delayed. However, in 1901, after the Joint Board had been in existence for ten years, the vice-Chairman was able to report * that "at present every authority has done something and has done its best."

Greater difficulties were experienced with the manufacturers in dealing with their trade effluents, as they could only be called upon to use "the best means in their power," as regards purification, and it often happened that they had not power at all to alter their business premises, in order to provide for the necessary purification works.

Speaking generally, however, the vice-Chairman of the Joint Committee was able to report that the manufacturers had realized their obligations and were gradually meeting them, but many cases occurred in which, after impounding a trade effluent for a week, sludge and water were let off with a rush into the river at a favourable moment (presumably when the watchmen were not likely to interfere).

* * * * * * *

The different streams forming the waters of the Ribble watershed furnish a very interesting study in relation to the disposal of the sewage and trade effluents of a thickly populated manufacturing district, and the question of river and estuarine pollution generally.

We are indebted to Mr. Halliwell, F.I.C., F.C.S., Chief Inspector of the Ribble Joint Committee, for the very interesting map of the watershed which we append, and also for the following particulars.

Regarding the amount of water descending the different rivers daily in dry weather, he says:—

> "I have only been able to obtain the true volume of one river, *viz.*, the Darwen, which by gauging is 12,000,000 gallons per day of 24 hours. From what I know of the flow of the other rivers I should estimate them to be as follows:—
>
> | | |
> |---|---|
> | River Calder - - - - - - | 25,000,000 gallons per day of 24 hours. |
> | River Ribble - - - - - - | 120,000,000 ,, ,, ,, ,, |
>
> I have given no estimate of the Douglas, owing to the stream being diverted in dry weather at a point marked A on the map to the Leeds and Liverpool Canal, and the water in the Douglas bed below that point is very small in volume. In wet weather, however, there is a very big flow."

The following table shows the volumes of the rivers and sewage works and manufacturers effluents:

VOLUMES IN GALLONS PER 24 HOURS.

River.	Sewage Effluents.	Manufacturers Effluents.	Total River Flow.
Calder - - - - - -	6,310,000	4,790,000	25,000,000
Darwen - - - - - -	5,830,000	3,700,000	12,000,000
Ribble (Non-Tidal) - - -	13,000,000	9,240,000	120,000,000
Douglas - - - - -	4,310,000	7,100,000	—
Crossens Channel - - - -	3,080,000	—	—

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* Evidence of Alderman Jonathan Phillips. Roy. Com. on Salmon Fisheries Rep. Part II., p.p. 660-661.

"In some cases manufacturers use river water which contains the effluents from sewage works and manufacturers' plants, for trade purposes, and in addition the waters are used by an extremely large number of mills for boilers and condensers."

In a later letter Mr. Halliwell says:—

"With reference to the volumes of the rivers I should estimate the flow of the Hodder at about 25,000,000 gallons. . . . . . I am anxious for you to understand that the only gauging taken was that of the Darwen, and the other figures are estimates; and the volumes of the effluents are also not too correct, as the figures are given by the different authorities, who often base their opinion upon a supply of 25 gallons per head per day—which I find is very frequently erroneous."

"It is, I fear, impossible to state the volumes of manufacturers' effluents derived from fresh water, and that derived from water taken from the river and used in manufacturing processes. You are, of course, well aware that in addition to the manufactories placed on the map there are hundreds of mills using water from the river for boilers and condensers, and, as I have stated both in reports and before the Commission, the method of abstraction and temperature of the resulting water play no little part in the condition of the streams."

At our suggestion Mr. Halliwell has been so good as to revise his figures regarding the dry weather river flows, etc., thus:—

River.	Nature of Water.	Dry Weather Flow per 24 Hours in Millions of Gallons.	Total Flow.	How Determined.
Hodder - -	River Water - - - - - -	About 25	25	Estimated.
Calder - -	„ plus Manufacturers' Effluents	„ 18½	25	„
	Sewage Effluents - - - - - -	„ 6½		
Darwen -	River Water plus Manufacturers' Effluents	„ 6	12	Gauged.
	Sewage Effluents - - - - - -	„ 6		
Ribble -	(Non-Tidal) River Water - - -	„ 57⅔	58	Estimated.
	Sewage Effluents - - - - -	„ ⅓		
		120	120	Estimated.

Mr. Halliwell has also kindly supplied us with the following analytical data:—

WATERS OF RIBBLE BASIN.

ANALYSES BY E. HALLIWELL, F.I.C., &c.

Date of Collection 1905.	Rainfall			Nature of Sample.	Parts per 100,000.									C.C. per Litre at N.T.P.	
					Matters in Solution.			Chlorine.	Nitrogen as			Oxygen Absorbed.		Dissolved Oxygen.	
	Pre-ceding Day.	Pre-ceding 2 Days.	Pre-ceding Week.		Loss on Ignition	Ash.	Total.		Free Ammonia.	Album-inoid Ammonia.	Nitrate.	3 Min-utes.	4 Hours.	When Collected	In Labora-tory next day.
March 22	0·00	0·00	0·32	River Calder at Junction with the Ribble.	13	25	38	4·2	0·156	0·041	0·0	0·24	0·72	5·9	4·8
April 18	0·01	—	0·29	River Ribble at limit of Tidal Influence.	11	15	26	3·0	0·058	0·016	Trace	0·06	0·26	8·3	8·1
March 3	0·00	0·01	1·16	River Darwen at Junction with the Ribble.	16	34	50	4·8	0·379	0·099	0·12	0·68	1·40	7·1	—
March 14	0·12	0·26	1·13	River Douglas as discharged to Canal.	21	59	80	6·6	0·206	0·041	0·12	0·58	1·02	—	2·94
”	”	”	”	River Douglas at limit of Tidal Influence.	15	48	63	6·4	0·074	0·033	0·16	0·44	0·68	8·5	7·7
March 22	0·00	0·00	0·37	River Douglas as discharged to Canal.	20	72	92	8·0	0·124	0·058	Trace	0·44	1·22	2·7	0·34
”	”	”	”	River Douglas at limit of Tidal Influence.	17	53	70	5·2	0·206	0·041	0·22	0·28	0·78	5·0	3·05

As the Ribble watershed was investigated by the Rivers Pollution Commission in 1868–1869, we hoped that by comparing the analytical data contained in their Report with Mr. Halliwell's results, valuable information would be gained regarding the past, compared with the present condition of the rivers.

But our expectations in this respect have been to a considerable extent disappointed, as the localities from which samples of the different river waters were collected were not the same in the two cases (with one exception). However, in the following table we give the results of the comparison, such as they are.

RIBBLE WATERSHED.

Comparison of Analyses made in 1868–1869, and in 1905.

[*Results in parts per* 100,000.]

River.	Where sample was collected.	When examined.	Total solids in solution.	Organic Carbon.	Organic Nitrogen.	Ammonia	Nitrates and Nitrites.	Chlorine.
Calder	Below Burnley - -	Aug., 1868	40·4	1·076	0·758	0·020	0	5·1
	Near Junction with Ribble.	March, 1905	38·0	—	(Albd.) 0·041	0·19	0	4·2
Douglas -	400 yards below Wigan Outfall.	„ 1869	64·3	0·749	0·141	0·260	0·013	4·0
	Below Wigan and as discharged into Canal at Gathurst.	„ 1905	86·0	—	(Albd.) 0·05	0·20	0·06	7·3
Darwen -	Below Blackburn -	„ 1869	41·5	2·127	0·295	0·219	0	3·6
	At Walton-le-Dale -	„ 1869	33·0	1·289	0·141	0·137	0·045	2·9
	At Junction with Ribble.	„ 1905	50·0	—	(Albd.) 0·099	0·46	0·12	4·8

The most striking feature in the two sets of figures is the difference between the organic nitrogen of the older series, and the albuminoid nitrogen of the newer, and while these two analytical factors are, of course, by no means identical, they are to some extent comparable, and it seems probable therefore (from the table) that the organic impurities in the waters in 1868–1869 were then much greater than in 1905.

The only samples collected in these two periods from practically the same locality, are the two last on the list, and, as it happens, both of these were collected in March, so that a closer comparison is warranted in the case of these samples than in that of the others.

From the higher proportion of solids in solution, ammonia, and chlorine found in 1905, the inference is warranted, we think, that the amount of original pollution (if the expression may be allowed) now entering the Darwen is greater than in 1869, but also that the relatively low figure at present found for the albuminoid nitrogen would seem to indicate that considerable progress has been made in purifying this original pollution before it enters the stream.

That the condition of the rivers in the Ribble watershed has improved is evident, we think, from the following extract from the Report of the Rivers Pollution Commission:

> "That the noxious qualities of polluted water are not removed by a flow of 10–12 miles is sufficiently evident to the senses in the case of the three rivers upon which we experimented in the Mersey and Ribble basins. They were all very offensive at the termination of the flow."

Whereas at the present time they are not only quite inoffensive, but in the majority of cases contain an amount of dissolved oxygen which is surprisingly high, and their beds also, as far as can be judged from an inspection, show no record of over pollution.

We learn from Mr. Halliwell that no systematic analysis of the rivers of the watershed have been made during the period that the Ribble Joint Board has held jurisdiction until 1905, when he commenced them.

This, if we may be permitted to say so, is to be regretted, as the results of such analyses would have afforded not only the clearest possible evidence of the condition of the waters over a considerable period, but would have also indicated in an unmistakable way the progress made towards improving their condition. In the absence of such analytical data, it is not possible to say with certainty what the Board's efforts have accomplished, and the discussion of the figures supplied us by Mr. Halliwell is attended with difficulties.

We propose, however, for the moment to leave the question of trade effluents out of consideration, and to regard the different rivers of the watershed as consisting of mixtures of sewage effluents and pure water. We propose, further, to assume that Mr. Halliwell's analyses were performed with dry weather samples. The following argument may then be employed :—

The Calder.—The total estimated daily dry weather flow of this river is some 25 million gallons, and this includes about 6½ million gallons of sewage effluents. On the assumption that the difference between these two figures, namely 18½ million gallons, is the volume of pure water in the river, then the stream as it enters the Ribble is composed of water, three parts; sewage effluents, one part—in round numbers, or in other words one quarter of the flow consists of sewage effluents.

The average composition of sewage is difficult to determine, but for reasons which one of us has given in evidence before this Commission,* the following figures may be accepted as at least approximately correct for town sewage :—

PARTS PER 100,000.

Nitrogen as :—		Oxygen Absorbed Test. (4 Hours at 80° F.)
Free Ammonia.	Albuminoid Ammonia.	
2·5	1·0	11·0—12·0

On the assumption that they apply to the case under consideration, a mixture of three parts of pure water and one of sewage would give an analysis :—

Nitrogen as :—		Oxygen Absorbed.
Free Ammonia.	Albuminoid Ammonia.	
0·625	0·25	2·75 – 3·0 say 2·875

Whereas Mr. Halliwell's figures for a sample of the Calder at its junction with the Ribble are :—

Nitrogen as :—		Oxygen Absorbed.
Free Ammonia.	Albuminoid Ammonia.	
0·16	0·041	0·72

These latter are in no case greater than one quarter of those preceding them, while in that of the albuminoid ammonia the amount is only one-sixth, so that in spite of trade effluents added, the total purification of the sewage would appear to be not less than 75 per cent.

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* Evidence of E. A. Letts given May 17th, 1905 (Fifth Report, Vol. II.)

The Darwen is a much more seriously polluted stream than the Calder, for the total daily dry-weather flow as gauged amounts to only 12 million gallons, whereas of this about 6 million consist of sewage effluents, or in round numbers the river as it enters the Ribble is composed of equal parts of water and sewage effluents. Extending the argument applied above as regards the Calder to this stream (the Darwen)—if the sewage were unpurified and reached the spot where the sample was collected—unchanged, the water should show on analysis—

Nitrogen as :—		Oxygen Absorbed.
Free Ammonia.	Albuminoid Ammonia.	
1·25	0·50	5·5–6·0 say 5·75

whereas Mr. Halliwell's figures are—

Nitrogen as :—		Oxygen Absorbed.
Free Ammonia.	Albuminoid Ammonia.	
0·38	0·10	1·4

Here the free ammonia is about one-third, the albuminoid ammonia one-fifth, and the oxygen absorbed about one-fourth, respectively, of the preceding figures, indicating on the whole, as in the case of the Calder, a purification of the sewage approaching 75 per cent., or of about 67 per cent. if the free ammonia alone is taken as the index.

The Douglas.—The daily flow of this river was not estimated by Mr. Halliwell, because, as already stated, a portion of its water is diverted into the Leeds and Liverpool Canal, but it receives some 4⅓ million gallons daily of sewage effluents, and if the averages of Mr. Halliwell's analyses are taken, the figures are—

Nitrogen as :—		Oxygen absorbed.
Free Ammonia.	Albuminoid Ammonia.	
0·152	0·036	0·92

which do not differ considerably from those which he obtained for the Calder.

The Ribble at the Limit of Tidal Influence.—The estimated daily dry-weather flow here amounts to about 120 million gallons, of which some 13 million consist of sewage effluents; or in round numbers one-ninth of the water is composed of these latter.

Supposing, then, as before, that the remainder is pure water, and that the original sewage has undergone no change, the water should contain—

Nitrogen as :—		Oxygen absorbed.
Free Ammonia.	Albuminoid Ammonia.	
0·28	0·11	say 1·28

whereas Mr. Halliwell's figures are—

Nitrogen as :—		Oxygen absorbed.
Free Ammonia.	Albuminoid Nitrogen.	
0·058	0 016	0·26

respectively.

In none of the three factors is the amount in the latter figures more than one-fifth of those preceding them, showing possibly the effects of self-purification, in addition to the artificial purification (if the expression may be permitted) accomplished at the different sewage works.

* * * * *

The argument employed above with reference to the figures supplied us by Mr. Halliwell is, it need scarcely be said, of a rough-and-ready kind, and involves several fallacies, of which the most important is, no doubt, that the very extensive pollution of the rivers caused by manufacturers' effluents is completely ignored. But at least it gives an idea of the *minimum* purification ultimately effected of the sewage of the district, and also, we venture to think, bears very satisfactory testimony to the good work which has already been accomplished by the Ribble Joint Committee, while in addition it appears to us to furnish a substantial argument in favour of the creation of similar boards in the different watersheds of the kingdom, whose duty it shall be to maintain the rivers under their jurisdiction in as pure a condition as possible.

THE RIBBLE WATERSHED IN RELATION TO FISH LIFE.

In spite of the extensive pollution of the Ribble above its tidal limit by the Calder and Darwen, and in the estuary by the Douglas, salmon and sea trout still ascend its waters; they are captured not only in the estuary, but also in the river itself, and continue to spawn in its upper reaches.

The watershed, in fact, is still a fishery district which is under the control of the Ribble Fishery Board.

The following particulars are taken from the Report of the Royal Commission on Salmon Fisheries.

In the year 1900, salmon were still fairly abundant in the estuary, and two years previously 530 were returned as caught by net during that season (a number which was possibly below that actually taken, owing to the difficulty in obtaining accurate returns from the fishermen), while 28 were caught by rod, that is to say, in the river itself.*

It was, however, stated that forty years previously there were from twenty to forty times the number of fish now found in the river, the witness who gave this information saying that in 1865 he himself had caught three salmon with rod and line in one day.† The same witness also stated that formerly the Hodder abounded with sea trout, and that thirty or forty could be taken in a day (presumably by rod) of an average weight of 2 lbs., whereas very few could now be caught. On the other hand, the Ribble is still a very good stream for ordinary trout and owing to the hatcheries belonging to the conservators, and also owing to private fishing clubs, these fish have considerably increased in number. Regarding the decrease in the number of salmon taken, it appears that the fishery above Preston was formerly let at £1,000 per annum, but it is now rented by the Ribble Fishery Board for £8 a year in order to keep the nets off the private water.

Regarding the condition of the rivers of the watershed (in 1900), in relation to fish life, the evidence was to the following effect :—

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* In connection with the above Mr. Halliwell writes to me as follows :—" I know for an absolute fact that during this Autumn (1906) one gentleman with the artificial fly landed three salmon in a day and another hooked three, landing two ; and fifteen salmon trout were also taken by one rod in one day on the Hodder."

† Evidence of T. Gustaves Garnett, Roy. Com. on Salmon Fisheries Rep., Part 2, p. 66.

Taking the south or left bank of the Ribble and beginning in the upper reaches of the river, fish can live in all the tributaries above Mitton; that includes the tributary passing through Clitheroe, Downham, and Chatburn. Taking the next tributary going downwards—the river Calder—there are fish as low down from its source as Burnley, but from Burnley it would be impossible for fish, even eels, to live owing to the pollution of its waters.*

The next tributary is the Darwen. Below the town of Darwen—and there is very little of the river above—no fish could live.

Regarding the north or right bank of the Ribble, none of the tributaries are seriously polluted, and fish inhabit them.

Further evidence was given that if, after a period of drought, a sudden rainfall occurred on the south side of the watershed affecting the manufacturing districts first of all, the waters of the polluted streams washed down accumulated impurities which occasion considerable damage to fish life, one witness going so far as to state that "every living fish is poisoned from the entrance of the Calder to the sea."

But if, on the other hand, the river Hodder comes down in flood first, there is a good chance of the fish getting up without being poisoned. As to the Douglas, it was stated that its waters would not support fish life on the main stream above Blackrod right up at the source, and that the other part of the river is in a very polluted condition, with probably no fish in it at all.

Regarding the causes of the decrease of fish in the watershed it was stated—

(1) That the largest difficulty arose from pollution.

(2) That the decrease (in salmon) was also partly due to overnetting in the estuary and the use of nets with too small a mesh. And further, that the close time during the fishing season was insufficient.

(3) The "Training Walls" placed in recent times in the estuary immediately below Preston in connection with the development of the town as a port act, first, in narrowing the river in the estuary, thus concentrating the sewage pollution; and secondly, in causing the nets to practically stop the ascent of fish, as they virtually extend from side to side.

(4) The abstraction of water from the upper reaches of the tributaries of the Ribble (especially from the Hodder and Darwen) for municipal purposes. In the case of the Hodder it was even suggested that this might be carried to such an extent that the river would cease to exist.

* * * * *

The amount of dissolved oxygen present in the waters of the Ribble and its tributaries is of considerable importance, not only in relation to fish, and especially of salmon, but also in connection with the question of fermenting organic matter.

Mr. Halliwell's figures are unexpectedly reassuring on this point, as they show a higher proportion of dissolved oxygen in nearly all the samples examined than might have been expected.

Thus he found that the Ribble at the limit of tidal influence contained 8·3 cc. per litre, and on keeping the water for 24 hours only 0·2 cc. were lost. The former figure corresponds with air saturation at a temperature of 8–9°c., while the slight loss on keeping shows that but little easily fermentable organic matter was present.

The river Darwen at its junction with the Ribble contained 7.1 cc. per litre, or over 85 per cent. of the air saturation value—a surprisingly high figure considering the nature of its waters, and the Calder at its junction with the Ribble 5·9 cc. per litre, or over 71 per cent. of the air saturation value.

It would therefore appear, from Mr. Halliwell's figures, that there is abundance of dissolved oxygen in the Ribble for the support of fish life, and that it is improbable that any material damage is done it in this respect by its tributaries, and Mr. Halliwell's figures also indicate that no nuisance is likely to arise from any of the rivers, with the possible exception of the Douglas.

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* Evidence of W. Naylor, Roy. Com. on Salmon Fisheries Rep., Part 2, p. 663.

VISIT TO PRESTON AND THE ESTUARY OF THE RIBBLE.

We visited this district on two occasions, namely, in August, 1904, and April, 1906. On the first of these occasions we were only able to devote two days to this interesting locality, and therefore our examination was necessarily of a very restricted nature. With the time at our disposal, it was in fact only possible to inspect (and in some cases to determine the dissolved oxygen in the waters of):—(1) The river Darwen at Walton near its junction with the Ribble. (2) The estuary of the Ribble from Lytham to Preston Quay—a distance of about nine miles; (3) The Ribble near its tidal limit at Preston; (4) The estuary of the Douglas from Tarleton Lock near its tidal limit to its confluence with the Ribble estuary.

On our second visit we again inspected the Ribble near its tidal limit, the Darwen at its junction with the Ribble, and part of the Calder as well as the Hyndburn, which is one of the chief feeders of the latter.

Before describing the results of our observations, we desire to take the opportunity of expressing our thanks to the authorities of Preston, and especially to Mr. Hamar, the Town Clerk, and Mr. Barron, engineer to the Harbour, both of whom assisted us in every way in their power on our first visit, made arrangements which enabled us to see as much as possible in the limited time at our disposal, and accompanied us to some of the places we wished to inspect. To Mr. Barron we are under special obligations, as he devoted a large share of his time to us, and placed the Harbour Launch at our disposal.

We should remark that the weather had been dry for some time previous to our visit, and that consequently the rivers were low and in a favourable condition for observing the effects of pollution. We are indebted to Mr. Halliwell for obtaining the following figures relating to the rainfall, which were recorded at Stoneyhurst.

Date.	Inches.
July 30th, 1904	0·000
„ 31st, „	0·050
August 1st, 1904	0·000
„ 2nd, „	0·000
„ 3rd, „	0·160
„ 4th, „	0·325
„ 5th, „	0·010

The rain which fell was mainly, if not entirely, caused by thunderstorms, one of which on the morning of August 4th was of especial violence, though of short duration.

On our second visit we were accompanied by Mr. Halliwell, to whom we are under many obligations, some of which we have already mentioned.

The Darwen.—On our first visit we inspected this river at Darwen Bridge on the evening of August 4th, and found that a good deal of water was coming down owing to the thunder showers, leading no doubt to considerable scour of the bed of the stream. The river at this point is about eighteen yards wide and apparently shallow. We were informed that a few days previously it was almost dry here, but at the time of our visit there was a strong current. The water was quite black, with some floating scum, but it was not offensive.

We collected a sample and found that it contained:—

Dissolved oxygen - - - - - 1·80 c.c. per litre at N.T.P.

On our second visit to the locality in April, 1904, we examined the Darwen at and a little above its junction with the Ribble. The weather had been showery, so that the stream was not at its lowest, but the water was not very high. It was brown and turbid, but had no smell. The bed, consisting of mud and sand, was brown, and when dug into was not black beneath the surface. There were in fact no signs of over pollution, and the condition of the river impressed us much more favourably than on our first visit.

The Ribble at Preston near its Tidal Limit.—The river is here a fairly broad but shallow stream, and the current is not very swift.

At the time of our visit in 1904 the water was, as already stated, very low, so that the effects of pollution should have been at their maximum. But yet the appearance of the river did not indicate extensive pollution. The water, if not absolutely clear, was sufficiently transparent to enable one to see the stones, etc., at the bottom quite distinctly at a depth of 2 feet or so, and green aquatic vegetation was present in fair quantity.

On our second visit in April, 1906, the water was somewhat higher and not quite so transparent. On this occasion, when we were accompanied by Mr. Halliwell, we walked up the southern bank of the river, and noticed that for some distance below its junction with the Ribble, the Darwen affected the former by discolouring the water for some distance across the stream, and also by leaving traces of a black scum along the bank. Crossing the Darwen we walked to the road bridge at Walton, and then crossed over the Ribble and continued our walk for a short distance up stream along the northern bank of the river, eventually returning to Preston on the same side, *i.e.*, northern. We carefully examined the bed of the river from time to time, which is stony and sandy, but could detect no traces of extensive pollution, such as any black deposit below the surface of the bed, or fungoid growths on the stones, etc.

On the whole we were very favourably impressed with the condition of the river, both as regards absence of marked signs of pollution and in relation to its fitness for fish life.

The Calder.—One of us inspected this river with Mr. Halliwell in April, 1906, near its junction with the Hyndburn, one of its chief feeders.

The Hyndburn, which, in addition to receiving the sewage effluents from Church, Accrington, Oswaldtwistle, Rishton, Clayton and Great Harwood, is also extensively polluted with manufacturers' effluents, is a small stream, perhaps 10 yards wide near its junction with the Calder, shallow, and fairly rapid.

At the time of our visit the weather had been somewhat showery, so that the water was not at its lowest.

The Hyndburn, although showing undoubted signs of pollution, had by no means, the appearance of being an over-polluted stream. Its water was brown in colour, and while somewhat turbid was not unduly so, and it had no foul smell. The bed of the stream was sandy and not muddy, and its surface was brown. Some of the stones in the bed (near the Clayton and Great Harwood sewage works) were, however, found to be black where they had been imbedded, and a little fungoid growth was seen on some of their upper surfaces.

The Calder, after its junction with the Hyndburn, receives no further pollution to speak of during its flow of two or three miles to Mitton, where it joins the Ribble. Its condition, therefore, just below the spot where it unites with the Hyndburn may be considered as representing its worst state as regards pollution.

We made a careful inspection of the river and its bed, both above and below this spot. Above, we found its condition unexpectedly good, in view not only of the extensive pollution to which it is submitted, but also of the statements made with regard to it by some of the witnesses examined before the Royal Commission on Salmon Fisheries.*

The water was fairly clear, stones, etc., on its bed being quite visible at a depth of at least 8 inches. Moreover, there was quite an abundance of green aquatic vegetation —a very significant sign. The bed, composed of stones, gravel and sand, was quite clean-looking, and when dug into there was no indication of any black deposit beneath the surface. Just below its junction with the Hyndburn, the appearance of the stream was not quite so good, but there were no signs of either present or past over-pollution. The only thing we noticed here at all suspicious was a layer of dry fibrous matter about ¼ inch thick, containing white maggots or worms, spread in patches over part of the river's banks which looked like an old sludge deposit—probably due to wool washings and sewer overflows brought down by storm.

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* Evidence of the Clerk to the Ribble Fishery Board, also that of Gustaves Garnett, Esq., Roy. Com. Salmon Fisheries, Part II., p. 61–66.

Estuary of the Ribble.—In order to inspect the estuary we went (in August, 1904) by railway to Lytham, a watering-place of some importance, distant about nine miles from Preston Quay, and, when the tide had risen sufficiently, returned to Preston in the harbour launch.

We arrived at Lytham at dead low water (neap tide), and made a careful examination of the shore, which consists of a broad stretch of remarkably clean-looking sand. Just at the margin of the water, however, there was mud and *débris* of vegetable matters entangled in it, chiefly leaves, which we were informed are washed down the river at certain seasons of the year in considerable quantities. The mud and leaves were black and offensive when dug into. But, broadly speaking, no evidence whatever of pollution was afforded by the condition of the foreshore, and green seaweeds were virtually absent. This can no doubt be explained by the effects of scour, as at the bar, about seven miles from Lytham, the tide rises 24 feet at springs and 17 at neaps, while at Preston itself the tidal range is from 4½–10 feet.

We inspected the Liggard Brook, a muddy channel which used to carry off the Lytham sewage, but now discharges chiefly the treated effluent. The mud banks of this brook were brown and not black on the surface, and there was no offensive odour. This spot we were informed is the worst to be found at Lytham as regards pollution. At the mouth of this brook we found a few fronds of *ulva*, the only specimens of the seaweed we saw in the estuary.

We examined a sample of water taken from the channel at dead low tide below Lytham pier and found it to contain :—

Dissolved oxygen - - - - - -	5·62 c.c. per litre at N.T.P.
Chlorine - - - - - - -	14·4 parts per 1,000.

It was, therefore, fairly salt and practically contained the quantity of oxygen corresponding with the air saturation figure.

When the tide had risen sufficiently we went on board the harbour launch and steamed up to Preston.

Just above Lytham we visited a (suction) sand dredger and examined the sand which was being raised from the channel. It was clean looking, but the scum rising from it had a disagreeable smell—not, however, like that of sewage.

As the river contracted, less sand was seen and the shores became muddy. About 3¼ miles below Preston we collected a sample of the water and found it to contain :—

Dissolved oxygen - - - - -	4·84 c.c. per litre at N.T.P.
Chlorine - - - - - - -	14·1 parts per 1,000.

The outfall from the Preston sewage farm is near this spot.

A little higher up the river we noticed a decidedly sewagy smell, and at Preston Quay the water was greasy on the surface, turbid, and generally dirty looking.

Heavy thunder showers had occurred a few hours previously, and it was suggested to us that this had led to a scouring out of the sewers and the escape of storm overflow water from them. Mr. Barron stated that the appearance of the river was worse than usual.

We collected a sample of water at Preston Quay and found it to contain :—

Dissolved oxygen - - - - - -	3·41 c.c. per litre at N.T.P.
Chlorine - - - - - - -	0·3 parts per 1,000.

Estuary of the River Douglas or Asland.

We examined this river in August, 1904, our starting point being Hesketh Bank station which we reached by train. This place is virtually at the head of the estuary, but the river is tidal several miles further up. We walked up stream to Tarleton Lock—the end of a branch of the Leeds and Liverpool Canal—and there collected and examined a sample of the river water which was brown and turbid and, as its examination showed, was unmixed with sea water.

Temperature of water - - - - 19·0° C.
Dissolved oxygen - - - - - 2·13 c.c. per litre at N.T.P.
Chlorine - - - - - - - 0·05 parts per 1,000.

The banks of the river were here muddy but brown on the surface; below the surface, however, the mud was black. A little green vegetation (of a low form) was found on the stones in the bed of the river.

The lock keeper gave us the following information:—

A year or two ago he saw both living and dead salmon in the river, but had seen none, either dead or alive, that year (1904). Nevertheless in his opinion the condition of the river has improved. Formerly eels were often seen near the lock, but not so many now. His idea being that formerly they sought refuge from the foul water of the river in the overflow from the canal, which consists of fairly pure water, but that now owing to the improvement in the condition of the water they do not require to do this.

He also told us that the water of the Douglas is coloured at times (no doubt from dye works' effluents), being, according to his account, sometimes merely milky and at others purple. In his twelve years' experience it had never been offensive.

After our examination of the stream at Tarleton we retraced our steps and, following the river towards the sea, arrived at its estuary, which may be said to commence at Becconsall a little below the Preston and Southport Railway. Here the western side is controlled by the Hesketh Embankment (erected for reclamation purposes), which extends to the Ribble Estuary and then along it seawards for some miles in a south-westerly direction. The enclosed or reclaimed land forms the "Hesketh Enclosure," which is farmed.

On the eastern side of the Douglas Estuary the land is a marsh.

The river channel in the estuary is narrow but well defined, at low tide its bed being muddy. We examined a sample of the water near the seaward extremity of the training wall—the tide not having then turned, and the stream consisting of fresh water only. We obtained the following results:—

Temperature of the water - - - - 21° C.
Dissolved oxygen - - - - - - 3·69 c.c. per litre at N.T.P.

The amount of dissolved oxygen is interesting in view of the previous determination at Tarleton Lock about 3 miles higher up. It is improbable that the composition of the water had materially changed during the interval, and it may be assumed, we think, that the difference in the dissolved oxygen was entirely due to aeration. This difference amounts to an increase of 1·56 c.c. per litre. We had no means of gauging the rate of the river's flow, but we estimated it to be not much more than a mile per hour, so that the water during a flow of about 3 miles and after an interval probably of from two to three hours had gained in dissolved oxygen from about 33 per cent. of the air saturation value to about 57 per cent.

The river was throughout its course between the two places of examination, so far as we could judge, very shallow, so that in that respect the conditions were favourable to aeration.

We may mention that when the tide commences to rise in the Douglas Estuary it does so with great rapidity, causing, during springs, a tidal wave or bore.

Aquatic vegetation seemed to be singularly absent both from the river and estuary. But in a land drain of the inner Hesketh Embankment, though sluice locked, we found *Enteromorpha intestinalis* in fair amount.

Our general impression of the whole Ribble Estuary was very favourable.

In spite of the extensive and populous district draining into it, and the varied industries contributing their trade effluents, no marked indications of pollution are to be found even a few miles below Preston, while at Lytham all signs have disappeared.

APPENDIX.

In a recent letter to one of us Mr. Halliwell writes as follows :—

"Many schemes for the extensions and alterations to sewage works and manufacturers purification plants are in hand and the work of construction is progressing and on completion should result in further material improvement in the condition of the river."

He has also kindly supplied us with the following additional analyses which are of interest :—

Samples taken to show effect of the River Darwen on the River Ribble.

PARTS PER 100,000.

Time.		Rainfall.			Chlorine.	Ammonia.			Nitrates in terms of Nitrogen.	Oxygen Absorbed.		Dissolved Oxygen when taken in c.c. per litre.	Dissolved Oxygen after 24 hours at 27°C.
		Preceding day.	Preceding 2 days.	Preceding week.		Free.	Alb.	Org.		In 3 minutes.	In 4 hours.		
	Samples taken April 3rd, 1906.												
12.15 p.m.	River Ribble before junction with the River Darwen -	·00	·00	·035	3·0	·11	·025		·12	·16	·22	7·5	6·4
12.30 p.m.	River Darwen at bridge above junction - - - -				5·0	·71	·08		·12	·32	·83	6·2	2·1
1.45 p.m.	River Ribble ½ mile below junction of River Darwen -				3·0	·13	·025		·12	·18	·28	7·3	6·28
	Samples taken April 5th, 1906.												After 48 hrs.
2.50 p.m.	River Ribble before junction with River Darwen - -	·00	·00	·00	3·2	·10	·04		·16	·10	·40	7·0	5·68
3.10 p.m.	River Darwen at bridge above junction - - - -				6·0	·54	·10		0	·40	1·30	4·6	.36
4. 0 p.m.	River Ribble ½ mile below junction of River Darwen -				3·4	1·06	·03		·16	·08	·38	7·0	5·27

River Ribble—Average Samples taken on April 19*th*, 1906.

PARTS PER 100,000.

Sample No.	Time taken.		Rainfall.			Total Solids.			Chlorine.	Ammonia.			Nitrates in terms of Nitrogen.	Oxygen Absorbed.		After Incubation.	Oxygen Dissolved.	
			Preceding day.	Preceding 2 days.	Preceding week.	Loss on Ignition	Ash.	Total.		Free.	Alb.	Org.		In 3 minutes.	In 4 hours.	Oxygen Absorbed 3 minutes	Same day.	After 24 hours at 27°C.
Wh. 1	3.15 p.m.	River Ribble at Preston at low water - -	·00	·02	·02	–	–	–	3·8	·15	·04	–	·20	·14	·40	·14	7·5	7·1
Wh. 2	3.45 p.m.	Do. do. - -	–	–	–	–	–	–	3·8	–	–	–	·20	·12	·40	·14	–	–
Wh. 3	4.15 p.m.	Do. do. - -	–	–	–	–	–	–	3·8	·15	·04	–	·20	·16	·40	·18	7·8	6·8
Wh. 4	4.45 p.m.	Do. do. - -	–	–	–	10	25	35	4·0	–	–	–	·20	·16	·42	·16	–	–
Wh. 5	5.15 p.m.	Do. do. - -	–	–	–	–	–	–	4·2	·18	·04	–	·20	·18	·44	·20	7·4	6·3
Wh. 6	5.45 p.m.	Do. do. - -	–	–	–	–	–	–	3·8	–	–	–	·20	·26	·42	·20	–	–
Wh. A	8.15 p.m.	Do. 10 mins. after first sign of tide	–	–	–	–	–	–	4·2	·17	·04	–	·20	·26	·44	·22	7·7	broken
Wh. B	8.45 p.m.	Do. 40 mins. do.	–	–	–	11	25	36	3·8	·16	·04	–	·20	·24	·50	·16	7·8	6·9
Wh. C	9.15 p.m.	Do. 70 mins. do.	–	–	–	–	–	–	4·2	·18	·04	–	·20	·30	·48	·24	7·7	6·4

Temperature : Air 11·5°C. ; Water 12·0°C. Tide time 9.20 p.m. ; height 22 ft. 7 ins. Weather fine.

Edward Halliwell, F.I.C.

SECTION 7D.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

THE RIVERS OUSE, AIRE, DON, TRENT AND HUMBER.

THE HUMBER AND ITS TRIBUTARIES.

TOPOGRAPHY

The Humber forms the estuary of the rivers Ouse, Aire, Don and Trent, and divides South East Yorkshire from Lincolnshire. It extends from its mouth at Spurn Head on the east coast of England for about 20 miles in a north-west direction to Skidder Ness, and thence in a westerly direction for a further 20 miles to Faxfleet.

The breadth of the Humber varies from 1 to 2 miles for the greater portion of its length, from west to east, and then, from about the neighbourhood of Hull, it increases to 4 or 5 miles at Great Grimsby, and to 8 miles near its mouth, where it is narrowed to 5 miles by the protrusion of Spurn Head on the north.

The Humber is connected by its tributaries, together with numerous canals, with the Mersey, the Thames, and the Severn.

THE TRIBUTARY RIVERS—OUSE, AIRE, AND DON.

Dr. H. Maclean Wilson, chief inspector of the West Riding of Yorkshire Rivers Board, has made careful examinations of the rivers Ouse, Aire, and Don, and the authors are indebted to him for courteously supplying to them the information which follows.

The river Ouse, for a great part of its course, where it is fed by the rivers Swale, Nidd, Ure, Wharfe and Derwent, is a fairly clean natural stream. In spite of some rather considerable pollutions by the sewage of towns and villages, there is nothing in its waters to prevent or destroy fish life. But near Goole, where it is joined by the Aire and the Don, it becomes seriously polluted, and it is a matter of yearly complaint that the gross pollution of these streams has not only destroyed fish life in them, but that their dirty waters have poisoned the whole of the waters of the Ouse where they join it, and prevent the passage of salmon and other fish trying to ascend from the Humber.

The Ouse, above the point where it is joined by the Aire, drains an area of some 2,636 square miles, and with its chief tributaries comprises a length of stream considerably over 450 miles, nearly the whole of which is available as breeding ground for salmon, if they were permitted to reach it. The Aire, with its nearly equal affluent, the Calder, drains an area of 810 square miles, within which lie nearly the whole of the towns and villages in which the woollen trades of the Riding are carried on, as well as many chemical works, collieries, paper works, and other premises from which grossly polluting liquids are discharged. The waters of the Aire and Calder, above their junction at Castleford, are grossly polluted by sewage and trade refuse, but between Castleford and Airmyn, near to which the Aire joins the Ouse, there is little additional pollution, and some purification takes place chiefly brought about by the deposition of polluting solids in the river bed. These solids are swept out into the Ouse by freshets, and thus that river is most poisoned at the time of floods, just when salmon are trying to ascend to the upper waters.

The Don drains an area of 682 square miles, within which lies much of the coalfield of the Riding, and in its upper reaches is seriously polluted by the sewage of towns and villages, more especially by the sewage of Sheffield. But the most serious possible pollution, with regard to fish life, is that by the discharge from mines of ochre water, which contains iron in suspension and solution, and free acid in such quantities as to be fatal to both fish and plant life. Between the most polluted stretch of the river and the junction with the Ouse, the river has, like the Aire, a long course in which it receives little further pollution, and in which a similar temporary deposit of polluting solids takes place. These solids are swept out into the Ouse when the river is in flood, and poison both bed and water of that river.

Table 1 shows the condition of the waters of the Aire, Calder and Don, after they have passed through the districts in which they are most grossly polluted, and the effect of a flood upon the Calder in stirring up and carrying forward the filth which has settled in the river bed. The first three analyses are averages of twelve analyses of samples taken quarterly from September, 1898, to June, 1901. The samples of flood waters from the Calder were taken during a high flood in November, 1901, the first after the exceedingly dry summer of that year, the rainfall at Wakefield being 2·81 inches in two days.

TABLE 1.—Analyses showing the Condition of the Waters of the Rivers Aire, Calder and Don, after they have passed through the Districts in which they are most grossly Polluted, and the Effect of a Flood upon the Calder in stirring up deposited Sewage Solids. The first three Analyses are Averages of twelve Analyses of Samples taken quarterly, from September, 1898, to June, 1901 (Maclean Wilson).

(Results expressed in Parts per 100,000.)

—	Total of Solids in Suspension and Solution.			Solids in Suspension only.			Chlorides (as Na Cl.)	Nitrogen as.			Oxygen absorbed in 4 hours at 80 F.
	Loss on Ignition.	Ash.	Total.	Loss on Ignition.	Ash.	Total.		Nitrates	Ammonia.	Albumenoid Ammonia.	
River Aire at Methley - - - - - -	11·38	45·70	57·08	2·33	2·16	4·49	10·64	·41	·661	·137	1·42
River Calder at Methley - - - - -	8·11	41·89	50·00	1·71	1·48	3·19	12·14	·36	·365	·064	·61
River Don at Conisborough - - - - -	10·19	69·34	79·53	·8	1·99	2·79	23·82	·41	·438	·040	·337
River Calder at Wakefield on 12th and 13th November, 1901, during a heavy flood after drought :—											
A. Taken while river rising 11.40 a.m. to 12.40 p.m.	28·0	426·4	708·4	276·0	382·0	658·0	10·25	Nil.	1·16	6·28	64·3
B. At height of flood 3.30 to 4.30 a.m. - -	60·6	177·2	237·8	57·0	160·0	217·0	3·75	0·14	0·25	0·89	8·76
C. While river falling 11.0 a.m. to 12.0 noon	10·4	37·6	48·0	5·2	17·6	22·8	3·75	0·35	0·10	0·11	1·28
D. While still falling 3.30 to 4.30 p.m. - -	12·0	36·8	48·8	4·4	17·2	21·6	4·0	0·31	0·08	0·10	1·26

The Aire empties itself into the Ouse at Airmyn, a place about 5½ miles above the junction of the Don with the Ouse. The banks of the Aire about Airmyn are almost perpendicular and are covered under high-water mark with a thick slimy mud. The width of the stream averages about 150 feet at low water, but the mouth of the river is divided into two portions by Asselby Island, around which the Aire waters are held up by the flood tides and which divides the flow of the waters as they pass up and down the channel.

The Ordnance map shows Rusholme on the Ouse about 1¼ miles above the main mouth of the Aire. From Rusholme to the Don mouth, 6¾ miles, the Ouse varies very considerably in width, being about 800 feet across at the mouth of the Don and 1,700 feet at Howden Dyke Island at high water. The navigation between these places is very difficult, as the depth varies owing to the presence of sand banks, which are frequently changing their position. The banks of the Ouse are very steep and are in many places covered with willows within high-water mark.

From Don mouth to Swinefleet, a distance of 2 miles, the banks of the Ouse are protected by training walls made of slag, which may possibly give rise to considerable pollution by sulphides. In fact, on many occasions a distinct odour of sulphuretted hydrogen has been noticed when drifting near these walls.

The channel of the Don near its mouth is quite artificial, it was made by Vermuyden in 1637, and is a straight cut with steep banks.

The rivers are influenced by the tides for a great distance above Goole—the Ouse as far as Naburn Locks, a distance of 27 miles; the Aire and Don 16½ and 17 miles above their respective junctions with the Ouse. The rate of flood and ebb varies very greatly. During spring tides the flow lasts about two and a quarter hours, with an ebb of nine and a quarter hours, and a period of quiescence of about half an hour at high and low water. During neap tides the flow lasts four hours and the ebb seven and a half hours.

Dr. Maclean Wilson has made the following tests in order to determine the amount of sea water brought up by these tides:—At a spring tide on October 29th, 1901, samples were taken at Swinefleet every five minutes during the two and a half hours of flow, and every fifteen minutes during the ebb of nine hours. Similarly, at a neap tide on November 4th, 1901, samples were taken at the same place every ten minutes during the flow of four hours, and every fifteen minutes during the ebb of seven and a half hours. The chlorides were estimated, and the following results were obtained:—

Spring tide.	Parts NaCl per 100,000.
Low water, 5 a.m.	70
„ „ 6 a.m.	310
„ „ 7 a.m.	960
„ „ 7.20 a.m.	1,490
High water, 8 a.m.	1,400
„ „ 9 a.m.	1,300
„ „ 10 a.m.	1,120
„ „ 11 a.m.	750
„ „ 12 a.m.	620
„ „ 1 p.m.	520
„ „ 2 p.m.	380
„ „ 3 p.m.	260
„ „ 4 p.m.	180
„ „ 5 p.m.	120
Neap tide.	
Low water, 9.50 a.m.	20
„ „ 10.0 a.m.	20
„ „ 11.0 a.m.	25
„ „ 12.0 n'n.	60
„ „ 1.0 p.m.	150
High water, 1.55 p.m.	370
„ „ 2.0 p.m.	400

Neap tide.	Parts NaCl per 100,000.
First ebb, 2.35 p.m.	520
„ „ 2.50 p.m.	540
„ „ 3.0 p.m.	480
„ „ 4.0 p m.	280
„ „ 5.0 p.m.	190
„ „ 6.0 p.m.	140
„ „ 7.0 p.m.	90
„ „ 8.0 p.m.	60
„ „ 9.0 p m.	30
„ „ 10.0 p.m.	25

Taking the amount of sodium chloride in sea water at 3,000 parts per 100,000, the above figures show that, while at the top of a spring tide the water at Swinefleet consists of an equal admixture of river and sea water, at low water of a neap tide there is scarcely any sea water present. At dead low water of a spring tide, on the other hand, there is still a small proportion of sea water present, and at the height of a neap tide there is, roughly, about one-fifth of sea water to four-fifths of river water.

During the spring tide the river rose 12 feet in the first hour of flow, 5 feet in the second hour, and 3 feet during the remainder. The first big rush of flood water is, therefore, practically the flooding back of the waters which have come down during the latter part of the previous ebb, and this is followed by a slower flow of water with a gradually increasing admixture of sea water. It is apparent from these results that the river water passes several times up and down the river channel before it becomes thoroughly intermingled with the sea water.

Dr. Maclean Wilson, in order to test the effects of the waters of the Aire and Don upon those of the Ouse, has made a large number of analyses, which are quoted in Tables 2, 3 and 4, of samples which were collected at the following points :—

(1) At Rusholme Grange, on the main stream of the Ouse, 1¼ miles above the mouth of the Aire.

(2) In the river Aire, at short and varying distances up the stream.

(3) At Skelton, on the Ouse, 3 miles below the mouth of the Aire, and 2½ miles above the Don.

(4) In the river Don, at short and varying distances up the stream.

(5) At Swinefleet, on the Ouse, 2 miles below the mouth of the Don.

These samples were taken at different tides, spring and neap, at different states of the tide, and, as far as possible, under different weather conditions, as will be seen from the accompanying tables

The methods of analysis employed by Dr. Maclean Wilson are those in common use. For the estimation of nitrites and nitrates the filtered liquids were taken, Griess's method being followed in one case and the phenol-sulphonic method in the other. The estimation of ammonia and oxygen absorbed was made in the well-shaken liquid containing the whole of its suspended matter.

Great difficulty was met in estimating the dissolved oxygen on account of the large quantity of warp or silt in suspension, for although after standing some time the greater part of the suspended matter settled, yet a very fine substance remained in suspension, and was difficult to remove, even by filtration.

After numerous experiments and various attempts at filtering without exposure to air, the following method was decided upon. Samples were collected in an aspirator bottle about 800 cc. capacity, by immersing the bottle in the river so that the water entered by the bottom opening, driving out the air at the top, until the bottle was brim full; the cork at the bottom opening was only removed when under the surface of the water, in order to avoid the risk of air entering along with the water, and to ensure absence of surface water. Into the bottle thus filled there was introduced: (*a*) 3 cc. of a saturated solution of aluminium chloride to which sodium carbonate had been added until a precipitate was just beginning to fall: (*b*) 3 cc. of a saturated solution of sodium carbonate.

The bottle was corked without allowing any air to enter, well shaken up and allowed to stand, when the precipitated hydrate of aluminium brought down the suspended matters very quickly and left a clear and colourless liquid. This supernatant liquid was syphoned into a 300 cc. bottle and Winkler's method used for the estimation of the dissolved oxygen, the determination being made at the time the sample was taken. This preliminary treatment was only adopted after a long series of experiments on waters containing varying known quantities of dissolved oxygen had shown that the amount present was not altered by the process.

Dr. Wilson notes in reference to his analyses, that the samples, with one exception, were taken during a period of great drought when the rivers were at their lowest, and therefore when there was least dilution of polluting matters. As already stated however, it is found on the other hand that there is under such conditions a large deposition of solids from the waters in the upper reaches of the rivers, and that it is during freshets that these accumulated solids are swept out into the Ouse, and this increased pollution during a freshet is well shown by the sample taken on November 12th, Table 3, when the rivers had been some twelve to fifteen hours in flood

TABLE 2.—Analyses of river samples collected near Goole during September and October, 1901, by Dr. Maclean Wilson.

(Results in parts per 100,000.)

September 3rd, 1901. Weather fine. Spring tide 18 ft. 1 in. at Goole.

No.	River and Place.	State of Tide.	Time.	Solids in Suspension. Total.	Solids in Suspension. Loss on Ignition.	Solids in Solution. Total.	Solids in Solution. Loss on Ignition.	Chlorides as NaCl.	Nitrogen as NH_3.	Nitrogen as Alb. NH_3.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	O_2 absorbed in 4 hours at 80° F.	Siliceous matter in Suspension.	Dissolved oxygen in c.c. per litre.*	Remarks.
1	Ouse at Rusholme -	2 hrs. ebb	p.m. 1. 0	66·72	7·12	290·0	43·0	211·0	0·014	0·09	0·0	0·04	0·97	36·8	2·00	River calm.
2	Aire at Airmyn -	2½ ,,	1.45	186·0	24·0	190·0	29·0	127·5	0·01	0·22	0·0	0·05	2·04	105·0	1·60	,, ,,
3	Ouse at Skelton -	4 ,,	3. 0	238·0	30·0	351·0	47·0	262·5	0·01	0·33	0·0	0·04	2·41	132·0	—	,, choppy.
4	Don at mouth - -	6 ,,	4.15	516·6	67·6	271·0	44·0	187·5	0·015	0·64	0·0	0·05	4·05	284·0	—	,, ,,
5	Ouse at Swinefleet -	7 ,,	5. 0	425·0	49·0	379·0	60·0	281·0	0·01	0·53	0·0	0·03	4·12	238·0	—	,, calm.

September 17th, 1901. Weather, slight drizzle during day, but no heavy rain ; water calm. Spring tide 16 ft. 4 in. at Goole.

No.	River and Place.	State of Tide.	Time.	Solids in Suspension. Total.	Solids in Suspension. Loss on Ignition.	Solids in Solution. Total.	Solids in Solution. Loss on Ignition.	Chlorides as NaCl.	Nitrogen as NH_3.	Nitrogen as Alb. NH_3.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	O_2 absorbed in 4 hours at 80° F.	Siliceous matter in Suspension.	Dissolved oxygen in c.c. per litre.*	Remarks.
6	Ouse at Rusholme -	2 hrs. ebb.	p.m. 12.15	53·6	5·6	355·0	42·0	262·5	0 015	0·08	0·0	0·10	1·10	30·4	2·50	River calm.
7	Aire at Airmyn -	2½ ,,	1.20	365·0	40·0	246·0	35·0	171·0	0·01	0·45	0·0	0·0	4·59	212·0	1·86	,, ,,
8	Ouse at Skelton -	4½ ,,	2·30	118·0	13·0	438·0	57·0	332·5	0·01	0·17	0·0	0·07	1·80	67·0	2·77	,, ,,
9	Don at mouth - -	6 ,,	4· 0	516·0	60·0	320·0	45·0	228 7	0·02	0·63	0·0	0·07	6·13	276·0	2·26	,, ,,
10	Ouse at Swinefleet -	7½ ,,	5·15	317·0	37·0	417·0	54·0	310·0	0·0	0·42	0·0	0·07	4·14	183·0	2·67	,, ,,

September 23rd, 1901. No rain, water calm. Neap tide 11 ft. 3 in. at Goole.

No.	River and Place.	State of Tide.	Time.	Solids in Suspension. Total.	Solids in Suspension. Loss on Ignition.	Solids in Solution. Total.	Solids in Solution. Loss on Ignition.	Chlorides as NaCl.	Nitrogen as NH_3.	Nitrogen as Alb. NH_3.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	O_2 absorbed in 4 hours at 80° F.	Siliceous matter in Suspension.	Dissolved oxygen in c.c. per litre.*	Remarks.
11	Ouse at Swinefleet -	½ hr. flood	a.m. 11. 5	60·2	6·5	68·0	6·4	23·0	0·17	0·10	0·01	0·22	0·61	32·2	2·30	River calm.
12	Don ½ m. above mouth	¾ ,,	p.m. 12. 0	24·0	2·4	109·0	10·4	37·0	0·60	0·07	0·015	0·19	1·09	14·0	4·12	,, ,,
13	Ouse at Skelton -	1½ ,,	1. 0	74·8	8·6	48·0	6·0	9·0	0·21	0·13	0·0	0·16	1·42	41·0	3·10	,, ,,
14	Ouse at Rusholme -	2 ,,	2.10	70·6	7·4	40·4	7·4	5·2	0·11	0·14	0·0	0·12	1·39	39·2	4·27	,, ,,
15	Aire 1¼ m. above mou'h	2½ ,,	3.20	85·6	10·4	42·4	4·4	7·0	0·14	0·14	0·0	0·14	1·48	46·8	3·85	,, ,,

	October 1st, 1901.					River very calm, very slight rain during day.									Spring tide 19 ft at Goole.
16	Ouse at Rusholme -	2 hrs. ebb	a.m. 11.30	47·0	5·0	471·6	54·0	360·0	0·0	0·06	tr.	0·24	0·84	26·5	1·37	Fine and calm.
17	Aire at Airmyn -	3½ ,,	p.m. 12.30	85·0	12·0	355·0	40·0	265·0	0·0	0·1	0·0	0·25	1·23	46·4	0·97	Calm ; slight rain.
18	Ouse at Skelton -	4½ ,,	1.30	222·8	28·8	592·0	65·0	465·0	0·0	0·27	0·0	0·25	3·09	129·4	1·92	,, ,,
19	Don at mouth -	5¾ ,,	2.45	691·6	90·0	464·6	36·0	360·0	0 0	0·94	0·0	0·24	8·35	388·0	1·58	Tide very fast.
20	Ouse at Swinefleet -	6½ ,,	3.35	359·4	36·0	598·0	42·0	460 0	0·02	0·56	0·0	0·25	4·84	209·0	1·62	Calm ; no rain.
	October 7th, 1901.					Weather fine, with strong wind.									Neap tide 13 ft. 11 in. at Goole.
21	Ouse at Swinefleet -	½ hr. flood	p.m. 12 15	78·0	5·0	53·0	5·4	15·3	0·28	0·15	0 0	0·08	1·48	43·0	4·51	Water very choppy.
22	Don ¼ m. above mouth	1¼ ,,	1.10	73·6	8·0	83·0	6·0	27·0	0·46	0·13	0·0	0·14	1·35	26·2	4·22	,, calm.
23	Ouse at Skelton -	1½ ,,	2.10	183·0	18·6	50·0	4·0	14·2	0·37	0·29	0·0	0·06	2·65	106·4	4 62	,, very choppy.
24	,, ,, Rusholme -	2 ,,	3.15	76·4	5·0	41·0	5·0	8·0	0·37	0·17	0·0	0·0	1·68	46·0	5·30	,, ,,
25	Aire 1¼ m. above mou'h	3¼ ,,	4.25	74·6	6·6	42·0	3·0	9·5	0·38	0·16	0·0	0·0	1·63	41·0	4·89	,, calm.
	October 14th, 1901.					Weather very fine, but cold, rivers dead calm.									Spring tide 16 ft. 4 in. at Goole.
26	Ouse ½ m. above Swinefleet.	1½ hrs. flood	a.m. 6.40	575·0	53·6	344·0	41·0	245·0	0·03	0·84	0·0	0·25	6·61	344·0	1·57	Tide very strong, river rising very rapidly.
27	Don ½ m. above mouth	2 ,,	7.5	663·0	57·0	276·0	30·0	200·0	0·04	0·83	0·0	0·23	7·30	405·0	1·23	Tide very strong.
28	Ouse at Skelton -	2 1/30 ,,	8.20	66·8	6·8	437·0	48·0	335·0	0·03	0·11	0·0	0·23	1·12	36·8	2·0	,, not strong.
29	Aire at Airmyn -	High water	8.55	88·2	8·2	167 0	20·0	110·0	0·05	0·12	0·0	0·20	1·35	50·0	1·01	No tide.
30	Ouse at Rusholme -	¾ hrs. ebb	9.40	60·0	5·6	163·0	20·0	105·0	0·09	0·09	0·0	0·18	1·01	30·0	1·13	Tide slowly ebbing.
	October 21st, 1901.					Weather cold and foggy, with slight rain.									Neap tide 10 ft. 8 in. at Goole.
31	Ouse at Rusholme -	2 hrs. ebb	p.m. 3.30	11·2	0·48	29·0	3·0	3·7	0·12	0·10	0·0	0·06	0·54	6·6	6·55	River calm and clear.
32	Aire at mouth -	2¾ ,,	4.0	7·84	0·24	32·0	3·4	4·2	0·15	0·05	0·0	0·07	0·51	4·4	6·63	Tide very low, sample taken just below mouth.
33	Ouse at Skelton -	3½ ,,	4.35	31·6	3·6	31·4	3·4	4·5	0·12	0·11	0·0	0·07	0·88	17·2	6·19	
34	Don at mouth -	4 ,,	4.54	48·8	4·2	35·6	5·0	6·7	0·15	0·18	0·0	0·09	1·22	28·4	5·85	Calm.
35	Ouse at Swinefleet -	4¾ ,,	5.35	97·2	9·2	36·0	4·0	8·7	0·07	0·23	0·0	0·09	1·90	54·0	5·29	,,
	October 29th, 1901.					Weather calm and fine, no rain on previous day.									Spring tide 19 ft. 11 in. at Goole.
36	Ouse at Swinefleet -	½ hr. flood	a.m. 5.45	421·0	45·0	333·2	46·4	245·0	0·03	0·81	0·0	0·10	4·51	252·0	3·13	Tide very strong, river rising rapidly.
37	Don outside mouth -	¾ ,, ,,	6.0	685 0	73·0	208·0	30·0	142·5	0·04	1·16	0·0	0·08	6·05	409·0	2·29	Tide very strong.
38	Ouse at Skelton -	70 mins. ,,	6.30	648·0	58·0	172·0	15·4	115·0	0·04	1·10	0·0	0·08	6·04	389·0	2·27	,, strong.
39	Aire at Airmyn -	1½ hrs. ,,	7.0	1,093·0	110·0	83·0	7·0	45·0	0·06	1·28	0·0	0·06	7·78	741·0	2·12	,, ,,
40	Ouse at Rusholme -	2 ,, ,,	7.35	704·0	80·0	142·0	13·0	92·5	0·03	0·94	0·0	0·12	6·10	424·0	2·23	Tide not so strong as at other places.

*By Winkler's method.

The foregoing tables of analyses are extremely interesting and instructive. On carefully studying the results, it will be seen that, while the spring tide samples are more affected by tidal water and contain decidedly smaller quantities of polluting matters *in solution* than the neap tide samples, they nevertheless contain smaller quantities of dissolved atmospheric oxygen, and absorb larger quantities of oxygen from acid permanganate. It is difficult to offer any explanation for this apparently anomalous condition except on the assumption, which has already been explained in the cases of the rivers Liffey and Thames,* namely that the de-aeration, and large absorption from permanganate, are due to polluting *solid matters in suspension* in a state of putrefaction.

As already noted, Dr. Wilson has observed that the waters of the Ouse at Swinefleet rise twelve feet in the first hour, five feet in the second, and three feet during the remainder of a spring flood tide. A rise of water so rapid must obviously produce an extremely powerful tidal current in the Aire and Don immediately above Swinefleet, and one quite sufficient effectively to stir up polluting solid matters deposited during the less powerful currents attending neap tides. That such a disturbance of solid matters from the beds of these rivers in the neighbourhood of the Ouse does in reality take place at flood spring tides is shown by Dr. Wilson's analyses Nos, 37 and 39, Table 2, when they are compared with Nos. 36, 38 and 40. The first two samples referred to were collected at the mouths of the Don and Aire respectively, and the three last named at different and intermediate points along the Ouse. The first two samples contained 685 and 1,093 parts of suspended solids per 100,000, while the three latter contained 421, 648, and 704 parts per 100,000 respectively.

On referring to the quantities ot suspended solids recorded in Table 2 for neap tide samples collected at the same points along the above three rivers, it will be seen that they are much less, varying between twenty-four and ninety-seven parts per 100,000.

It is evident from these results that the disturbance of the beds of the rivers in the localities referred to is comparatively nil at neap tides as compared with spring tides.

In all probability the especially gross pollution of the Ouse by the Aire and Don which has been noticed by Dr. Wilson during freshets after dry weather is much more largely due to suspended solid matters in a putrefactive condition, than to matters in solution. The latter would be largely diluted by the flood waters (compare the analyses recorded in Table 1). Further evidence in reference to this question will be described a little later on.

The degree of aeration in the spring tide samples is generally below the minimum allowable for the protection of fish life †; that in the neap tide samples in Table 2 is generally above this limit. It is evident, however, from the results recorded in the two succeeding Tables 3 and 4 that the waters of the Aire at low water spring tides are sometimes at least decidedly polluted by matters in solution as well as by suspended solids, and de-aerated to a degree which renders them unfit for the support of fish life.

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* Section I., Chemical Changes, etc., pp. 83–91. See also p. 133. † Section I., Chemical Changes, etc,, p. 66.

TABLE 3.—Analyses of River Samples collected near Goole in October and November, 1901, by Dr. Maclean Wilson.

(Results in parts per 100,000.)

River Aire at low water, spring tide.

River and Place.	State of Tide.	Hour.	Solids in Suspension.		Solids in Solution.		Chlorides (as Na Cl).	Nitrogen.				Oxy. absorbed in 4 hrs. at 808 F.	Siliceous matter in Suspension.	Dissolved Oxygen cc. per litre (Winkler).	Remarks.
			Total.	Loss on Ignition.	Total.	Loss on Ignition.		From Free and Saline Ammonia.	Albumd. Wanklyn.	Nitrous.	Nitric.				
Aire at Airmyn - 13/10/01	After 6$\frac{3}{4}$ hrs. ebbing. Height of high tide 16$\frac{11}{22}$ ft.	p.m. 3·20	98·56	7·36	56·6	6·0	14·2	0·93	0·22	Nil.	Nil.	2·08	58·0	1·42	Calm, and misty, no rain.
Aire at Airmyn - 28/10/01	After 8$\frac{1}{2}$ hrs. ebbing. Height of high tide 17$\frac{7}{12}$ ft.	p.m. 4·45	97·0	8·0	69·0	6·0	18·0	1·07	0·29	Nil.	Nil.	2·42	55·0	1·32	Calm, slight rain on previous day.
Aire at Airmyn - 12/11/01	After 6$\frac{1}{2}$ hrs. ebbing. Height of high tide 16$\frac{2}{12}$ ft.	p.m. 3·30	572·0	74·0	69·0	6·0	20·0	1·24	0·82	Nil.	0·1	7·36	326·0	2·79	Heavy rains, but these had not affected the flow of the river. Water calm.

TABLE 4.—Analyses of River Samples collected near Goole, November 13th, 1901, by Dr. Maclean Wilson.

(Results in parts per 100,000.)

Spring tide $17\frac{9}{12}$ ft. at Goole.

Heavy rain on this and previous day. River Aire in high flood for first time for several months and very black and disagreeable. Tide very strong. Wind very strong.

River and Place.	State of Tide.	Hour.	Solids in Suspension.		Solids in Solution.		Chlorides (as Na. Cl.).	Nitrogen.				Oxy. absorbed in 4 hrs. at 80° F.	Siliceous matter in Suspension.	Disolved Oxygen c.c. per litre (Winkler).	Remarks.
			Total.	Loss on Ignition.	Total.	Loss on Ignition.		From Free and Saline Ammonia.	Albumd. Wanklyn.	Nitrous.	Nitric.				
Ouse at Rusholme	After $2\frac{1}{2}$ hrs. ebbing - -	a.m. 11.40	165·0	10·0	32·0	6·0	3·2	0·046	0·144	Nil.	0·12	1·71	110·0	6·00	River calm and in usual condition.
Aire at mouth -	After $3\frac{1}{4}$ hrs. ebbing - -	p.m. 12.10	162·0	16·0	30·0	5·0	3·5	0·42	0·32	Nil	0·23	2·61	101·0	0·38	River very choppy and in high flood. Water very black and shows well-marked lines of junction with the Ouse.
Ouse at Skelton -	After $4\frac{1}{2}$ hrs. ebbing - -	12.45	567·0	55·0	29·0	4·0	3·5	0·18	0·81	Nil	0·14	6·28	382·0	3·24	River choppy.
Don at mouth -	After 7 hrs. ebbing - -	3.5	493·0	57·0	54·0	7·4	15·0	0·36	0·67	Nil	0·24	5·33	331·0	3·95	Tide strong but water calm.

Ouse at Swinefleet : Boat broke down, sample could not be taken.

CONDITION OF THE WATERS OF THE HUMBER AND TRIBUTARIES IN 1904.

The authors of this Report made an inspection of the Humber from the Ouse at the junction of the Aire down as far as North Killingholme Haven on August 30th, and 31st, 1904, and they have to express their obligations to the corporation of Hull for the courteous assistance which they received from that body. The authors were provided with a steam launch and with the services of a Goole pilot for navigating the upper waters of the Humber, which are extremely difficult owing to the constant shifting of the position of the sand-banks.

They were accompanied on their first day's inspection by Councillor W. Hakes, F.R.G.S., member of the North-East Fishery Board, Councillor G.L. Scott, J.P., Deputy Chairman of the Water Committee, and Mr. F. W. Bricknell, Assoc. M. Inst. C.E., Assistant Engineer to Hull. These gentlemen rendered the authors much valuable assistance from their local knowledge of the Humber and of the districts lying on its banks.

It was considered desirable, as the time at the disposal of the authors for the purpose was very short, to select ebbing tides as offering the best water conditions for collecting typical samples for examination. The tides at the time were passing from springs to neaps, and high water at Hull on August 30th was at 8.46 a.m., and just fifty-nine minutes later at Goole. It was therefore decided to commence with the examination of the lower portions of the Humber, and to leave that of its upper portions and tributaries to the second day.

The particulars of the samples collected and the results of analysis are recorded in the succeeding Table 5, the second day's samples being placed first for convenience of illustration.

The dissolved oxygen and chlorine were determined immediately on collection ; the former by Letts' modification of Mohr's ferrous sulphate method,* the latter by the ordinary silver method.

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* Section on Field Work, p. 221, *et seq.*

TABLE 5.—Analyses of Samples of the Tidal Waters of the Rivers Ouse, Aire, Trent and Humber, collected August 30th and 31st, 1904.

August 31st, High Water at Goole 10.17 a.m.

Gases expressed in cc. at O°C., and 760 mm. bar., per litre ; other constituents as parts per 100,000.

No.	Particulars of Samples.	Distances below mouth of River Aire.	At time of collection.				13 days after collection of samples ; the samples being kept out of contact with the air.						
							Dissolved gases.			Nitrogen as—			
		Miles.	State of tide.	Temp. C.	Na Cl.	O_2	O_2	N_2	CO_2	NH_3	N_2O_5	N_2O_3	Organic.
1	River Ouse just above mouth of River Aire - -	—	¾ hour ebb	17·0	8·3	1·72	0·47	14·09	53·33	0·0	0·23	0·007	0·04
2	River Aire at mouth - - - - - - -	—	½ " "	17·0	50·0	2·16	0·52	14·08	55·09	0·001	0·26	0·0	0·037
3	Abreast Howden Dyke - - - - - -	1·5	1 " "	17·0	58·0	2·01	0·29	14·18	53·85	0·001	0·3	trace	0·035
4	River Ouse just above Goole - - - - -	4·0	1½ " "	17·0	207·0	3·60	—	—	—	—	—	—	—
5	River Ouse just above mouth of Trent - - -	12·0	2½ " "	17·0	464·0	4·35	1·91	13·57	54·27	0·002	0·25	0·0	0·056
6	River Trent at mouth - - - - - - -	12·5	2¾ " "	17·0	505·0	4·36	1·17	13·46	57·94	—	—	—	—
7	River Humber abreast Whitton Ness - - - -	16·0	3 " "	17·2	762·0	4·89	—	—	—	—	—	—	—
			August 30th, High Water at Hull, 8.46 a.m.										
8	River Humber abreast Read's Island, South Channel -	20·0	4 hour ebb	17·8	1073·0	5·34	1·42	13·17	57·61	0·0035	0·1	0·0	—
9	Ditto, 15ft. below surface - - - - - - -	20·0	4 " "	17·2	1243·0	—	0·64	12·83	58·65	0·005	0·19	0·0	0·035
10	River Humber abreast Barrow Haven - - - -	26·0	5¼ " "	17·2	1292·0	5·31	1·35	13·00	59·74	0·0015	0·21	0·0	0·043
11	River Humber mid-channel abreast east extremity Alexander Dock estate, and East District Sewer Outfall of Hull.	29·0	6 " "	16·8	1360·0	5·46	2·31	12·76	55·93	0·001	0·15	0·0	0·04
12	River Humber, abreast Killingholme Haven - -	36·0	1¼ " flood	16·8	1810·0	5·49	4·48	12·64	55·27	0·005	0·13	0·0	0·045
13	Ditto, 21ft. below surface - - - - - -	36·0	1¼ " "	16·2	1990·0	—	4·10	12·47	52·97	0·001	0·1	0·0	0·04

NOTE.—The state of the tide has been taken from the time of high water at Goole for samples 1 to 7, and from that of high water at Hull for samples 8 to 13. High water at Goole is 59 minutes later than at Hull.

All the samples except the last three, Nos. 11, 12 and 13, contained considerable quantities of brown clay and sand in suspension.

At the same time samples were collected in bottles of the form designed by Adeney * for the purpose of keeping their contents out of contact with the air for subsequent examination by his aeration method.† With reference to Letts' volumetric method for the determination of the dissolved oxygen, it is of practical importance to note here that no difficulty was met with from the suspended matters in the samples analysed, that is to say they did not interfere with the end reaction, as Dr. Maclean Wilson found that they did when using the Winkler method.

SALINITY OF THE WATERS OF THE HUMBER.

On reference to the results given in Table 5, it will be found that the sodium chloride determinations show that the approximate ratios of fresh to sea water, taking the amount in pure sea water at 3,000 parts per 100,000 was as follows :—

Nos.		Fresh water	:	Sea water.
1.	Ouse above mouth of Aire - - - -	Trace only of sea water.		
2.	Aire at mouth - - - - - -	59	:	1
3.	Ouse abreast Howden Dyke - - - -	49	:	1
4.	„ just above Goole - - - - -	14	:	1
5.	„ above mouth of Trent - - - -	6	:	1
6.	Trent at mouth - - - - - -	5	:	1
7.	Humber abreast Whitton Ness - - -	3	:	1
8.	„ „ abreast Read's Island - - -	2	:	1
9.	„ 15 feet below surface - - - -	3	:	2
10.	„ abreast Barrow Haven - - -	3	:	2
11.	„ abreast East District sewer outfall, Hull	6	:	5
12.	„ abreast Killingholme - - - -	1	:	2
13.	„ 21 feet below surface - - - -	1	:	2

It will be observed from the above figures that during the ebb average tide the proportion of sea water in the Ouse just above the mouth of the Aire was exceedingly small, and that it increased very gradually down stream until at North Killingholme Haven, a distance of 36 miles, it occurred in the proportion of 2 : 1 of fresh water.

The results for the bottom samples, Nos. 9 and 13 when compared with the corresponding surface samples, Nos. 8 and 12, show that the fresh and sea waters in the Humber are well mixed even in calm weather, throughout their depth, and that they exhibit in this particular a marked contrast to the waters of the Liffey Estuary,* in which the fresh waters remain on the surface of the sea water so persistently in calm weather.

SUSPENDED MATTERS IN THE WATERS OF THE HUMBER.

The waters of the Humber retain the brown colour which is so characteristic of those of the Ouse as far down stream as North Killingholme Haven, where they begin to assume the ordinary green colour of clean tidal waters.

The brown colour is caused by quantities of silt, or, as it is locally called, "warp," in suspension. These suspended matters are composed of clay and sand, and are much employed for improving land by flooding it with the waters, whereby, as the authors were informed, clayey soils are lightened, and as much as a foot in depth can be added to them. On the Hull side of the Humber and some miles below it much land has been reclaimed. On the other hand, at other parts of the coast land is being washed away.

It is obvious that where the tidal currents are sufficiently strong to stir up solid matters of this kind and to bear them in suspension for long distances, they could do the same for polluting solid matters, and it is not improbable, having regard to the enormous quantities of such matters which are discharged into the upper reaches of the Humber and to the fact that the whole of the sewage of Hull and of Great Grimsby is discharged into the Humber in the crude condition at all states of the tide, that they are very widely distributed in small quantities throughout the waters and along the bed of the Humber.

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* Section on Chemical Changes, etc., fig. 2, p. 97. ‡ *Ibid.*, p. 96.

AERATION OF THE WATERS OF THE HUMBER.

The results of the dissolved oxygen determinations show that the aeration of the waters of the Ouse from the junction of the Aire with it down to the neighbourhood of Howden Dyke, a distance of about 1½ miles, was well below the minimum limit of aeration possible for the support of fish life. But at Goole, a distance of 4 miles down stream, it just reached this limit, and gradually but steadily increased to 5·49 cc. oxygen per litre at North Killingholme Haven, which as already stated is about 36 miles below the mouth of the Aire. But even at that point the waters were not saturated. Mixed sea and fresh water in the proportions of 2 : 1 in which they there existed would hold in solution, when saturated at 16·8° C., 6·07 cc. oxygen per litre,* or if taken, as is usually done in practice, as one half the dissolved nitrogen, the volume of oxygen required for saturation would be 6.32 cc. per litre.

It will be observed that the last two samples recorded in Table 5 were collected on the flood tide one and a quarter hour after low water at Hull. They were collected in the channel about 9 miles above Great Grimsby and about 15 miles above the mouth of the Humber. It is evident from the results of analysis of these two samples that the flood waters, at least during the earlier hours of the tide return in a slightly de-aerated and polluted condition.

POLLUTION OF THE WATERS OF THE HUMBER.

The fact, that the aeration of the waters of the Humber was found to be well above the minimum limit possible for the support of fish life, proves that at the time of examination they could not have been seriously polluted, and the results recorded in Table 5 for those samples that were kept out of contact with the air for thirteen days, proves that, although they did suffer from some pollution, still it was of a slight and innocuous character which presented no danger to fish life.

The minimum loss of oxygen on keeping for thirteen days out of contact with the air was 1·25 cc. (No. 1) and the maximum 3·96 cc. (No. 10), oxygen per litre. The maximum loss allowable for third class tidal waters of the composition of sample No. 10, which, from the quantity of sodium chloride contained in it, consisted of two parts of fresh and one of sea water, when kept for forty-eight hours out of contact with the air, is shown in Section 1, p. 65 (Table 24) and p. 67, to be equal to (48 × ·047) + 2·7 = 5·0 cc. oxygen per litre.

These figures indicate that the rate of reduction of aeration of the waters of the Humber on account of pollution was less than the rate of absorption of oxygen which they would exert from the atmosphere.

As regards the character of the polluting matters, it will be observed on reference to Table 5 that neither carbon nor nitrogen fermentable substances were found in the sample which was collected from the Ouse above the mouth of the Aire, after it had been kept thirteen days out of contact with air, and only traces of ammonia were found in the other samples. It is therefore safe to assume that the dissolved oxygen which was absorbed during the time of keeping out of contact with the air was mostly, if not wholly taken up by nitrogen fermentation, and that the carbon fermentation stage,† of the polluting matters originally present must have been completed, or nearly so, at the time of collection.

With reference to this question, it must be noted that it is possible that part of the oxygen which was absorbed in the case of some of the samples was taken up by the oxidation or fermentation of minute quantities of solid polluting substances in suspension. It will be observed that the bottom sample No. 9 showed a larger reduction of aeration on the one hand, and slightly larger quantities of ammonia and of carbon dioxide on the other hand, than the corresponding surface sample, No. 8, which goes to show that the former sample at least was slightly contaminated by organic matters. Having regard to what has been stated with reference to the fermentation of the organic substances originally present in solution having been completely fermented at the time of collection, it is difficult to suggest any explanation for this last observation, except to suppose that the slight increase in pollution of the bottom sample was due to suspended organic matters rather than to organic matters in solution. Had an increased pollution been observed in the surface sample, it would have indicated no doubt the presence of polluting organic substances in solution, since surface tidal waters are usually found to be more polluted by matters in solution than bottom tidal waters, but it was not.

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* See Section 1, p. 59. † Section 1, p. 44.

In concluding this reference to the results given in Table 5, it may be pointed out that they support the conclusion which was drawn from the analyses of Dr. Wilson—that comparative low state of the aeration of the waters of the Aire and Don at their junction with the Ouse, during spring tides, is due rather to suspended solid matters in a state of putrefaction than to organic matters in solution.

THE DISCHARGE OF CRUDE SEWAGE FROM HULL AND FROM GREAT GRIMSBY.

Hull is situated on the left bank of the Humber about 22 miles above its mouth, The population of Hull is 253,000 (1901) ; and the volume of sewage daily discharged in dry weather was in 1904, 12,000,000 gallons.

The sewage is diluted with a considerable quantity of condensing water from works on the River Hull. Trade effluents are negligible ; few tenements or small houses which were built prior to 1903 have w.c's.

The whole of the sewage is discharged into the Humber in the crude condition at all states of the tide. The outfalls are two in number. They discharge from the face of the river walls, 9·5 and 10 feet below the Ordnance Datum, which is 10·1 feet above low water and 12·37 below high water, of ordinary spring tides. The tidal currents are rapid, ranging up to 7 miles per hour, and they are at right angles in direction to that of the outfalls.

The authors collected a sample of surface water in the path of the sewage, and about 150 yards below the West District outfall, from which two-thirds of the Hull sewage is discharged.

The water was very dirty, and the path of the sewage plainly discernible from the large number of gulls which were flying over it and from the floating excrements which were plainly visible.

The aeration of this sample was equal to 2·88 cc. oxygen per litre, and the salinity to 1,340 parts sodium chloride per 100,000.

The bed along the path of the sewage was brown on the surface but black underneath. The banks of the river in the neighbourhood of Hull were brown and muddy, but they did not seem to be seriously polluted.

Enteromorpha in small amount was noticed on the jetty at Hull, and also some brown seaweed, otherwise very little seaweed was observed by the authors along the Humber.

It did not appear to the authors that the sewage from Hull was causing any serious or permanent pollution anywhere beyond the immediate neighbourhood of the outfalls, and this was not surprising considering the immense volume of the tidal waters passing up and down the river—the minimum width of the river is 1½ miles abreast of Hull—and the velocity and directions of the tidal currents which are at right angles to that of the outfalls. But it did appear to them that the outfalls should be extended so as to discharge the sewage into deep water at all states of the tide, and at some distance from the foreshore of Hull. It was evident to them that the positions of these outfalls along the face of the river wall was in opposition to ordinary sanitary precautions.

Great Grimsby is situated on the right bank of the Humber at its broadest part, and about 6 miles above its mouth. The population was 63,119 in 1901, and the sewage probably exceeds 1,250,000 gallons dry weather flow per day. There are two outfall sewers, the main one discharging about nine-tenths of the sewage, and a small one ; there is also a third one from the adjacent township of Cleethorpes. The sewage is discharged from all outfalls in the crude condition at all states of the tide.

The current is quick during the outgoing tides and sluggish or stationary on the incoming.

The outfalls are situated about low-water level of neap tides, or about 4·75 feet below the Ordnance Datum. Low spring tide is 4·25 feet below the outfalls, and high spring tide is 15·75 feet above outfall.

It is stated by Dr. Newby* that the main outfall is "in hot weather undoubtedly a nuisance, and the backing up of the sewage on the foreshore is a danger to which the attention of the authority has been frequently drawn."

Mr. H. G. Whyatt states that as in the case of the Liffey, the ebb waters from the lower portion of the Humber are not brought back by the flood tide. He further states that during the rise of the tide, a period of rather more than six hours, the discharge sewage is backed up, and for a portion of the time is spread or held in suspension over nearly the whole of the foreshore of the town. After the tide recedes, the foreshore is sometimes covered with about ½ inch of ooze, or slimy mud, and occasionally the deposit is even thicker, but this is more probably caused by the action of the wind, the waves and the tide upon the clay held in suspension in the water which comes down from the Trent and the Ouse, since at other times, varying with the strength of the wind and the height of the tide, the shore is quite clean, and covered only with hard sand. A quantity of foul slime, however, is always deposited at the mouth of the outfall and within a few feet thereof, but the radius of the foul area is very small.†

It is thus evident that owing to the strength of the tidal currents and to the enormous dilution of them by tidal waters, that the sewage matters are quickly disposed of, and probably do not cause any nuisance beyond that referred to by Dr. Newby and Mr. Whyatt. The remedy against the nuisance complained of would, no doubt, be a more favourable site for the outfalls, or to restrict the discharge of sewage from the present ones to the first four or five hours of the ebb tide.

GENERAL CONCLUSIONS.

(1) The waters of the Ouse immediately above Goole are de-aerated by polluting matters brought down by the waters of its tributaries, the Aire and Don, to such an extent that they are incapable of supporting fish life except during neap tides under dry weather conditions.

(2) The de-aeration of the waters of this portion of the river Ouse is greater during the ebb and flood of spring tides than during those of neap tides. This anomalous condition appears to be due to the presence in decided quantities of polluting *solids in suspension* in these waters, the result of the stirring effect on the bed of the river of the powerful tidal currents which obtain during the former tidal seasons. They appear to be present in very small quantities during neap tides, when the tidal currents are much less powerful.

(3) During freshets after dry weather, solid matters in a putrefying condition are brought down by the rivers Aire and Don, and they poison both the bed and waters of the Ouse and render them unfit for the support of fish life.

(4) The waters of the rivers Aire and Don do not generally appear to be seriously polluted with unfermented organic matters *in solution*, at their junctions with the Ouse in dry weather. There is evidence, however, to show that they are at times.

(5) Notwithstanding the enormous pollution of the upper waters of the tributaries Aire and Don by discharge into them of sewage, trade wastes, and ochre water from mines, the waters of the Humber from the point of junction of the Trent with it are only slightly de-aerated, and there is evidence to show that the bed of the Humber is also free from serious pollution. There is no reason to regard either the waters or the bed of the Humber

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* *See* Appendix, p. 489.

† "Proceedings of the Institution of Civil Engineers," Vol. 147, Part I., 1902, p. 85.

as either dangerous to public health or dangerous to fish life, except, possibly, in the immediate vicinity of the outfalls from Hull and from Great Grimsby.

(6) The positions of the outfalls of Hull and of Great Grimsby afford practical illustrations of the dangers of discharging crude sewage too close in shore, even when the tidal currents are rapid and favourable in direction for its rapid dispersion, and when the volume of tidal water is enormous compared with that of the sewage discharged into them.

(7) As in the case of the Liffey Estuary, clean sea water flows into the Humber with every flood tide, but owing to the great distance the tide travels up the Humber and its tributaries, nearly 70 miles, the river waters must obviously be carried several times up and down with the tide before they escape into the open sea.

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SECTION 7E. F. G. & H.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

MANCHESTER SHIP CANAL, AND THE RIVERS EDEN (CARLISLE), TAMAR, PLYM, AND THAMES.

MANCHESTER SHIP CANAL.

The waters of this canal afford another instructive study of pollution. The total length of the canal is 35½ miles. From Manchester to Latchford Locks, a distance of 14½ miles, the canal is fed by the waters of the rivers Mersey and Irwell; this portion of the canal also receives the effluent waters from the sewage purification works of Salford and of Manchester.

Below Latchford Locks to the entrance at Eastham, about 6 miles from Liverpool, the waters are affected by tidal waters. The length of this portion of the canal is about 21 miles. The entrance locks at Eastham maintain the water level in the canal nearly to mean high water level, 14 feet 2 inches above the Liverpool Ordnance Datum.

When the tides rise above this height the lock gates are open, and the tide flows up to Latchford, giving an additional depth of 7 feet at high spring tides. This water is returned to the Mersey through large sluices at Randles Creek and at the junction of the river Weaver with the canal.

The minimum depth of the canal throughout its length is 26 feet. The minimum width at bottom is 120 feet. At the locks and at other parts the width is however considerably increased.

The total rise to the level of the docks at Manchester from the ordinary level of the water in the tidal portion of the canal below Latchford is 60½ feet. It is obtained by an average rise of about 15 feet at each of the sets of locks at Latchford, Irlam (7½ miles nearer Manchester), Barton (2 miles above Irlam), and Mode Wheel (3½ miles above Barton Locks).*

Condition of the Waters of the Manchester Ship Canal.

Although very satisfactory results have attended the efforts of the Mersey and Irwell Joint Committee towards the prevention of the pollution of the rivers and streams in the Mersey and Irwell watershed, much still remains to be done, and the waters which flow into the canal are still heavily polluted and wholly unfit for the support of fish life.

An appreciation of the nature and extent of the pollution to which these rivers are liable and of the efforts which have been made to prevent or mitigate pollution, may be gathered from the following particulars as to population and number of manufactories on each of the main rivers and their tributaries and as to the sewage purification works in operation :—

—	Number of Manufactories.	Population.
Rivers Irwell and Roach	286	1,105,094
River Irk	45	324,206
River Medlock	15	283,407
River Mersey	98	789,396
Total	444	2,502,103

Practically all the local authorities have sewage works in more or less efficient operation, and particulars as to the methods of treatment adopted by each authority will be found in the Appendix to this Section.† The information in it has been brought up to date May, 1904.

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* These particulars have been taken from the description of the canal by the consulting engineer to the Manchester Ship Canal, Sir E. Leader Williams; "Encyclopædia Britannica," Vol. 26, p. 542.

† The particulars in this Appendix and all the information given in this Section as regards the condition of the Mersey and Irwell have been most courteously supplied to the authors by Mr. R. A. Tatton, M.Inst.C.E., chief inspector to the Mersey and Irwell Joint Committee.

The following table by Mr. Tatton gives the number of manufacturers in each industry where purification works are necessary. The portion of Derbyshire which drains into the river Mersey is included :—

Class of Pollution.	A. Efficient Works.	B. Works Constructed but not Efficient.	C. Works being Constructed.	D. No Treatment Adopted.	Total.
Print Works	38	10	—	—	48
Dye Works	88	32	—	—	120
Bleach Works	56	17	—	2	75
Waste Bleach Works	5	4	—	—	9
Paper Works	19	7	—	—	26
Paper Stainers	3	—	—	—	3
Tanners and Leather Dressers	5	3	—	1	9
Fellmongers	1	4	—	—	5
Woollen Trades	44	15	—	—	59
Silk Trades	2	—	—	—	2
Slack Washing	9	2	—	—	11
Soap Works	1	4	—	—	5
Stone Polishers	7	2	—	—	9
Chemical Works	13	5	—	—	18
Breweries	3	8	—	1	12
Unclassified	12	20	—	1	33
Total	306	133	—	5	444

Under column B are included many works where the surroundings are too limited to allow of efficient purification plant being put down.

The progress made between the years 1893 and 1904 in mitigating the pollution by trade wastes is indicated in the succeeding summary :—

——	Lancashire and Cheshire, October, 1893.	Lancashire and Cheshire, May, 1904.	Lancashire, Cheshire and Derbyshire, May, 1904.
Works with efficient purification plant	45	278	306
Works with plant constructed, but not efficient	77	126	133
Works being constructed	77	—	—
No treatment adopted	191	5	5
Total	390	409	444

In addition to these a large number of manufactories drain into the sewers, and the trade waste from them is dealt with by the local authority.

Mr. Tatton states in his report to the Mersey and Irwell Joint Committee for 1904 that, "Although the progress made with the work on the whole has not been unsatisfactory there is a great deal yet to be done and some of the rivers, especially the Irk and the Roach, are still in a highly polluted condition. Many of the sewage works are far from efficient, as shown by column 16 in the Appendix. Column 16 gives the percentages of samples taken which come within the limit of impurity, and gives an approximate idea of the efficiency of each works."

A large number of analyses by Mr. Scudder of sewage effluents from the sanitary authorities in the Mersey and Irwell watershed has already been recorded in Tables 32 and 33, pp. 79–84, Section 1.

Mr. Tatton further states in the same report that, "The most serious pollution at the present time is from storm water, as anyone who will inspect one of our rivers after a thunderstorm, following a period of drought, can verify. Accumulations of solid matter take place in the sewers during dry weather; these are scoured out by the first flush of heavy rain and passed to a great extent, by means of storm overflows, into the rivers and thence into the settling tanks formed by the Ship Canal and docks."

The authors of this report made an inspection of the waters of the canal on August 6th, 1904, with the kind assistance of Mr. Hunter, the chief engineer to the Ship Canal, who courteously placed a steam launch at their disposal, and with that of Dr. Gilbert J. Fowler, who accompanied them and afforded them valuable information as to the topography of the canal and of the adjacent estuary of the Mersey and as to the condition of its waters. He also most kindly made some analyses for them.

The authors commenced their inspection at Throstle Nest Dock, immediately above Trafford Bridge, Manchester.

The waters of the canal at this point were inky black in colour and emitted an odour of sulphuretted hydrogen, although the authors were informed by Mr. Hunter that they were in a better condition than usual owing to heavy rains which had fallen during the previous few days. It need scarcely be stated that they contained no dissolved oxygen and that fish life was quite impossible in them.

The canal waters remained unchanged in appearance down to Latchford Locks, and no further tests were made.

As already stated, tidal waters affect the canal below Latchford Locks, and their influence quickly became apparent. The black colour rapidly disappeared and the waters assumed a brown, muddy appearance. At the same time they rapidly became aerated, as will be seen from the following analyses of samples of the water which were collected at the time :—

High water 6.27 a.m. at Liverpool. Very strong wind blowing up canal. Dissolved oxygen expressed in cc., at N.T.P., per litre, other constituents in parts per 100,000.

——	Time.	T.	O_2 absorbed in 4 hours.	Nitrogen as		Cl_2	Dissolved Oxygen.
				NH_3	Alb. NH_3		
Manchester Canal.							
Throstle Nest Docks -	10.30 a.m.	19·2	—	—	—	—	0·0
One mile below Latchford	3.0 p.m.	19·2	0·86	0·60	0·062	612	2·07
Abreast Randles sluices -	4.45 ,,	19·2	0·60	0.47	0·038	1,010	2·50
Abreast Weaver sluices -	6.0 ,,	19·2	0·50	0·43	0.02	980	5·25

Note.—The determinations of "oxygen absorbed" and free and albuminoid ammonia were kindly made by Dr. Fowler.

It will be seen from the above chlorine determinations that the river waters of the canal become mixed with a considerable proportion of sea water about a mile below Latchford, and that at Randles sluices the river and sea waters are mixed together in about equal proportions. The aeration of the waters at the same time rises to 2·07 and 2·50 cc. oxygen per litre at these points respectively.

At the Weaver sluices the proportion of sea water was apparently not quite so large, but the aeration of the waters had increased to 5·25 cc. oxygen per litre. This rapid increase in aeration was no doubt due to the very high wind which was blowing up the canal at the time.

A more complete examination by the aeration method of a sample of the non-tidal waters of the canal, collected just below Irlam Bridge in October, 1905, will be found recorded and discussed in Section 1, Table 35 and pp. 86–88. The results show that the water would have to be diluted with a little more than three times its volume of fully aerated sea waterat 18°C. to produce a mixture on the large scale in which the rate of absorption of dissolved oxygen from all causes, under calm weather conditions, would not exceed the maximum allowable rate suggested for third class tidal waters, viz., 5·30 cc. oxygen per litre in 48 hours.*

When allowance is made for the high wind which prevailed at the time the above samples were collected and for the fact that the samples collected at the Randles sluices and at the Weaver sluices consisted of equal mixtures of sea and polluted non-tidal waters, it may be taken that the estimated dilution of the polluted canal waters with three times its volume of sea water would be found correct for large volumes of water under calm weather conditions.

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* See Section 1., p. 68.

APPEN

(Being a revision to date (May, 1904) of the Appendix 3 in Volume 3, Interim Report, Royal Commis

MERSEY A

PARTICULARS AS TO THE METHODS OF SEWAGE TREATMENT ADOPTED BY THE LOCAL AUTHORITIES IN THE ME

NOTE.—The samples have been taken over a period of two years, 190

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.*	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth an Character Filtering Material.
COUNTY BOROUGHS—		£						
Bolton (Astley Bridge Outfall Works) -	175744	770,287	8,000	Dry weather flow, 160,000 gallons per day.	3 tanks. Total capacity 180,000 gallons.	Lime copperas and alumino ferric.	3 filters. Total area 364 square yards, 439 gallons per square yard.	(1) 5 ft. to 6 cinders gravel; 3 ft. cin and gra (3) 1 ft. 6 cinders.
Bolton (Hacken and Rhodes farm) -			160,000	5,000,000 gallons.	3 settling tanks. Total capacity 2,884,613 gallons.	Ferrozone	None	None
Bury - -	58,028	261,876	Approximately 47,500.	1,750,000 gallons.	10 circular tanks. Total capacity 600,000 gallons.	Alumino ferric and ferrozone.	15 filters. Total area 9,060 square yards, 193 gallons per square yard.	3 ft. coke clinkers.
Manchester -	578,438 (includes portions of various outside districts).	3,532,321	574,800 (includes portions of various outside districts).	About 25,700,000 gallons average daily dry weather flow.	6 open septic tanks, each 300 ft. by 100 ft. by 7 ft. (average depth). Total capacity 7,800,000 gallons. 5 precipitation tanks. Total capacity 6,200,000 gallons.	Milk of lime and solution of copperas for a portion of the flow.	51 contact beds. Total area 25½ acres. 29 storm beds. Total area 27 acres.	Contact b 3 ft. 4 screened c kers; st beds, 2 ft. 6 unscreen clinkers.
Oldham	139,497	472,219	Practically all.	4,500,000 gallons.	12 tanks. Total capacity 2,073,600 gallons and 2 Detritus tanks.	None	32 filters. Total area 48,400 square yards, 92 gallons per square yard.	Average de 3ft., co posed of ca fully scree engine ash so that dust or or rubbish any kind be put the beds, of screen clinker fr Destructor

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* For character of trade waste in Sewage, see Appendix 3, Colum

Sewage Disposal, and supplied by the chief inspector, Mr. R. A. Tatton, M.Inst.C.E.).

WELL WATERSHED.

d Irwell Watershed, derived from Information supplied by the Authorities to the Joint Committee.

e limit of impurity is one grain per gallon of oxygen absorbed in four hours.

(9) Method of sing Filters hether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Intermittent	None	—	Carted away by farmers and others and used as manure.	3	5	8	63	
—	130 acres laid out in filtration plots, Subsoil land, loam, sand and gravel, and land drained 6 ft. deep.	38,461	Mechanically pressed and disposed of to farmers. 1,000 tons annually.	13	4	17	24	
ntermittent. ontact beds.	No land used. Total area 45½ acres.	—	Pressed, farmers cart away at present time.	5	6	11	55	8 tanks. Total capacity 600,000 gallons, and 4 acres bacteria beds are in course of construction.
termittent. Vith excessive flows. Storm beds used as streaming filters.	None	Contact beds 500,000, Storm beds 350,000.	Sludge taken out to sea.	38	7	45	16	3 open septic tanks and 20½ acres of contact beds in course of construction. 297½ acres of land at Carrington and Flixton and on the bank of the Ship Canal purchased for extension purposes. At present about 65 per cent. of the total flow is being filtered.
termittently. The beds are illed, allowed o stand full or a certain eriod, emptied, and then llowed to remain empty or some time efore being illed again.	None	—	Pressed, farmers in the neighbourhood take it when it is pressed; remainder used for filling up a large valley at the works.	7	8	15	53	The filtration area is being increased, and a scheme for dealing with the storm water is being prepared.

. 3, Interim Report, Royal Commission on Sewage Disposal.

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mers

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
County Boroughs —*continued.*								
Rochdale (Castleton Moor Works) - -	83,114	379,162	6,000	300,000 gallons.	3 precipitation tanks. Total capacity 112,500 gallons.	Alumino ferric	5 filters. Total area 480 square yards.	4 filters, con posed of cok and clinker 3 ft. deep from 2½ in. t ¼ in. Low level filte composed o gravel 7 in and clinker 1 ft. 11 in.
Rochdale (Roch and Sudden Outfall Works) -			Approximately 65,000.	2,000,000 gallons dry weather flow at present.	8 tanks for Roch outfall, capacity 1,410,000 gallons; and 3 tanks for Sudden outfall, capacity 300,000 gallons. Total capacity 1,710,000 gallons.	Alumino ferric	2 percolating filters. Total area 400 square yards. Also 5½ acres of bacteria contact beds are now nearly completed (4½ acres in use).	9 ft. deep, con posed of ga coke whicl has had al pieces smalle than 1½ in. re moved. Contact beds, 2 ft 9 in. dee (average) filled witl graded clinkers.
Salford - - -	228,903 Estimated.	970,895	218,244	Dry weather flow 8,000,000 gallons.	10 tanks, average 110 ft. long by 77 ft. wide Total capacity, 4,750,000 gallons.	Lime and copperas.	5½ acres of filter beds have been in use since 1902.	5 ft. and 8 ft deep crushe clinkers Average ½ i diam.
Stockport (including Reddish) - - -	95,709	385,864	—	2,750,000 gallons.	8 tanks. Total capacity 1,000,000 gallons.	Lime and iron sulphate, alumino ferric at night.	1 acre of filter beds in use. 5 acres in course of construction.	3 ft. 3 in. of deep screened clinkers.
Non-County Boroughs—								
Ashton-under-Lyne (including Hurst U.D.C. and a small portion of Limehurst R.D.C.)	52,373	204,917	52,000	About 1,500,000 gallons.	7 tanks. Total capacity 1,858,493 gallons.	Alumino ferric and ferrozone.	28 filter beds 2·40 acres first contact; 28 filters 2·40 acres second contact; 9 storm filters 1·54. Total area 6·34 acres.	In first contact beds about 3 ft. 10 in. composed of 12 in. on bottom of burnt cinder ballast, 2 ft. 5 in. of cinder media passed by 2 in. and rejected by ½ in., and the top 6 in. passed by ½ in. and rejected by ⅛ in. The storm filtering media is of the same materials, the centre layer being only 1 ft. 6 in. deep.

Irwell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of ing Filters ether Intermittent or ontinuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
termittent	2 acres	—	Air-dried on sludge filter beds.	6	3	9	33	Additions and extensions to these works are about to be commenced.
ntinuous rough re- olving arms. ontact beds termittent.	60 acres	—	Pressed, and cake taken by farmers.	17	5	22	23	
nerally 2 urs' run and hours' rest uring 24 ours.	None	On the filter beds from 1,000,000 to 3,000,000.	Sludge taken out to sea.	20	20	40	50	The roughing filters forming part of this system are not yet completely fitted up.
termittent	44 acres	—	Part pressed and part pumped into lagoons.	1	8	9	89	
ermittent	About 1¼ acres	—	Pressed					

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mers

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Non-County Boroughs—*cont.*								
Eccles - - -	34,369	138,750	Approximately 34,000.	1,250,000 gallons dry weather flow.	2 detritus tanks, 2 settling tanks. Total capacity 650,000 gallons.	None	—	—
Glossop - - -	Estimated to deal with 30,000.	78,000	21,000	About 500,000 gallons dry weather flow	6 circular tanks. Total capacity 118,000 gallons.	Alumino ferric	4 roughing filters, area 240 square yards; 10 fine filters, area 1,000 square yards; and 373 square yards of ash filters. Total area 1,613 square yards. 309 gallons per square yard.	2 ft. 9 in. polarite sand, &c.
Haslingden, Rawtenstall and Bacup Outfall Sewerage Board.	72,101	284,089	68,000	1,575,000 gallons.	4 tanks. Total capacity 1,825,000.	None	16 filters. Total area 2,400 square yards.	3 ft. deep clinker cinders. Further 1,000 square yards in course of construction.
Heywood - -	25,461	105,678	23,500	800,000 gallons dry weather flow.	6 tanks. Total capacity 710,000 gallons.	Alumino ferric	12 filters. Total area 1,325 square yards.	4 ft. engine ashes and coke.
Hyde - - -	32,766	106,000	About 32,000.	About 1,250,000 gallons.	8 tanks. Total capacity 2,000,000 gallons.	Lime and protochloride of iron during the day, alumino ferric at night.	15 filters. Total area 5,190 square yards (when complete). 240 gallons per square yard.	Total depth 9 ft. of gas coke.
Leigh and Atherton Joint Sewerage Board.	60,300 (Estimated).	239,590	About 61,200 (including part of Abram).	About 1,500,000 gallons dry weather flow.	8 tanks. Total capacity 1,500,000 gallons.	Lime and sulphate of iron.	6 filters. Total area 1,760 square yards.	3 ft. 3 in. rough clinker and cinders.
Macclesfield -	34,624	106,996	27,400	608,888 gallons.	5 tanks. Total capacity 450,910 gallons.	Alumino ferric	2 roughing filters. Total area 117 square yards.	3 ft. to 3 ft. 9 in. of coke.
Middleton - -	25,178	81,422	23,220	1,000,000 gallons.	3 tanks. Total capacity 120,000 gallons.	Ferrozone	6 filters, 600 square yards. 2 bacteria beds, 2,470 square yards.	3 ft. polarite gravel and sand. 3 ft. clean 1 in. mill cinders.

nd Irwell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters (whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
—	61 acres	20,491	Dried in open lagoons and disposed of on the land.	2	7	9	78	
Intermittent	—	—	Run into sludge lagoons.	0	9	9	100	12½ acres of land have been purchased but are not used for filtration.
Intermittent and continuous.	30 acres	—	Pressed	6	6	12	50	
Intermittent	5 acres	—	Pressed and taken by farmers.	5	10	15	67	Additional works proceeding. Heap Bridge outfall works nearing completion.
Continuous	None used	—	By pressing, and afterwards taken by farmers.	9	0	9	0	Additional works nearly complete.
Intermittent	* 112 acres	—	By pressing, and afterwards taken by farmers.	3	5	8	63	* Including about 27 acres of land laid out for treatment of storm water.
Continuous	50 acres	—	Pressed and dealt with on land.	8	7	15	47	A scheme for additional filtration works is in hand.
Continuous Intermittent	—	—	Pressed and taken by farmers.	2	6	8	75	Two bacteria beds having a total area of 1¼ acres are constructed, and are being fitted with 3ft. of mill cinders and under drains. Application is being made to Local Government Board for borrowing powers to cover the cost of constructing long lengths of sewers to connect some of the outlying hamlets to the sewerage system.

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mers

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Non-County Boroughs—*cont.*								
Mossley - -	13,452	62,000	13,000 to 13,452	350,000 gallons.	6 tanks. Total capacity 504,600 gallons.	None	11 filters. First contact area 838 square yards, 417 gallons per square yard. Second contact 600 square yards.	3 ft. first contact coke limestone pebbles, &c. second contact 4 ft. coke ashes, limestone, and sand.
Stalybridge and Dukinfield Joint Sewerage Board.	46,603	175,369	About 52,500.	1,500,000 gallons dry weather flow.	22 tanks. Total capacity 1,200,000 gallons.	None	9 filters. Total area 13,666 square yards.	Day flow through beds 3 ft. deep of coke and natural sand and soil.
Audenshaw Urban District Council (portion of District treated).	6,939	39,904						
Urban District Councils—								
Abram - - -	6,306	38,494	5,520	65,000 gallons.	6 tanks. Total capacity 42,000 gallons.	None	18 filters, and storm water roughing filters. Total area 2,720 square yards.	2 ft. 8 in. to 3ft. 9in. deep, composed of graded engine ashes.
Alderley Edge	2,856	22,460	2,900 (includes few outside population)	225,000 gallons dry weather, 500,000 gallons wet weather.	3 detritus tanks 13,500 gallons.	—	3 filters, 700 square yards.	Cinders 3 ft. 3 in. deep.
Altrincham -	16,831	87,329	18,000 (includes some outside population)	800,000 gallons dry weather flow	Catch pit and 2 sets of settling tanks. Total capacity 500,000 gallons.	None		

and Irwell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters (whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Each filter works 8 hours and rests 16 hours per 24 hours.	None at present	—	Pumped into lagoons.	2	1	3	33	
Intermittent	20 acres	—	Pressed and taken by farmers.	0	4	4	100	
Intermittent Filters capable of holding 3 days' liquid sewage, but are worked in sections, thus giving considerable rest to the beds. About one-half of the beds are in use at one time in 8 to 10 hours shifts The sewage is filtered 3 times over.	About 5 acres	—	Used on the land.	0	7	7	100	
Intermittent	6½ acres	34,500	Sold by contract to neighbouring farmers for a small sum.	2	9	11	82	A scheme for additional works is in hand.
—	69 acres	11,594	Used upon land not irrigated.	2	5	7	71	Total area of land 150 acres.

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey a

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Councils—*cont.*								
Ashton-in-Makerfield.	800 (Within Watershed.)	113,292 (U.D.C. District.)	800	Dry weather flow, 8,000 gallons.	2 tanks. Total capacity 10,000 gallons.	Alumino ferric	3 filters, total area 35 square yards.	2 filters, tot depth abou 3 ft., made u as follows :— 12 in. sand 12 in. san and polarit equal parts 5 in. sand an 4 in. gravel 3 in. stone an agricultural tiles; 1 bac teria bed.
Ashton-on-Mersey.	5,563	33,624	5,100	165,000 gallons.	2 tanks. Total capacity 7,000 gallons.	None	—	—
Aspull - - -	8,387	23,951	—	Have no sewage works. Sewage sent to Wigan.				
Audenshaw -	7,216	41,611	Part of the sewage dealt with by the Manchester Corporation and part by the Stalybridg					
Blackrod -	750 (Within	876 Watershed.)	750	7,500 gallons	None.	—	—	—
Bollington -	5,244	15,192	Scheme before Local Government Board.					
Bowdon - -	2,788	28,747	2,500	138,250 gallons.	3 tanks. Total capacity 34,537 gallons.	None	—	—
Bredbury and Romiley (Bredbury).	3,607	39,747	Works designed to treat sewage from a population of 4,000.	80,000 gallons dry weather flow.	5 open septic tanks. Total capacity 120,000 gallons.	None	18 filters. Total area 3,012 square yards.	9 coarse and 9 fine filters filled with clinker 4 ft. deep.
Bredbury and Romiley (Romily).	3,500		3,205	64,100 gallons dry weather flow.	6 detritus tanks, worked as open septic tanks. Total capacity 11,550 gallons.	None	10 filters. Total area 1,740 square yards.	6 coarse and 4 fine filters filled with clinker 4 ft. deep.
Chadderton -	26,000 Estimated.	98,491	About 18,000.	800,000 gallons.	6 tanks. Total capacity 730,000 gallons.	Alumino ferric	12 filters. Total area 1,351 square yards.	4 ft. engine ashes and clinker.
Cheadle and Gatley.	8,222	61,119	About 7,115.	About 222,300 gallons.	6 tanks. Total capacity 222,000 gallons.	Alumino ferric	Total area 320 square yards (about half the sewage is dealt with in the filters).	Sand, gravel, and polarite.
Compstall - -	875	4,714	—	—	No scheme			

rwell Watershed, derived from information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters (whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Intermittent	About 4 acres	—	Used on the land by the farmers.	0	4	4	100	
—	About 8½ acres	19,410	Dried on land and given away to farmers.	0	8	8	100	
nd Dukinfield	Joint Outfall Bo	ard.						
—	17¾ acres	422	On land	0	3	3	100	
—	About 7 acres, set out in beds and planted with willows.	19,750	To farmers	1	7	8	88	The settling tanks merely intercept the grosser solids. A scheme for additional works is in hand.
Intermittent ouble contact.	2 acres							
Intermittent ouble contact.	2 acres	—	Taken by farmers.	0	10	10	100	
Intermittent	9 acres	—	Pressed into cake and given to farmers.	0	17	17	100	
Intermittent	18½ acres	—	Air dried and given to farmers. Was formerly pressed; but it has been found most farmers much prefer air-dried sludge.	0	10	10	100	

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Councils —*cont.*								
Crompton (Cowlishaw).	13,427	54,196	1,500	37,500 gallons.	2 circular tanks, each 14 ft. diameter, 9 ft. deep. Total capacity 17,318 gallons.	Ferrozone	4 filters. Total area 133 square yards, 282 gallons per square yard.	2 ft. polarite
Crompton (Newhey).			8,000	900,000 gallons dry weather flow, including manufacturers' refuse water.	3 tanks, each 50 ft. by 40 ft. Total capacity 225,000 gallons.	Alumino ferric and lime.	6 filters. Total area 760 square yards, 1,184 gallons per square yard. In addition to the above, there is a septic tank and 2 bacteria beds, area 178 square yards, for treatment of sand washing water.	2 ft. 9 in. polarite.
Denton - - -	15,347	58,956	14,600	370,000 gallons dry weather flow.	5 tanks. Total capacity 1,190,000 gallons.	Lime	5 filters. Total area 1,200 square yards, 308 gallons per square yard.	2 ft. 6 in. 2 polarite and sand; 4 ft. 3 in. 1 cinders; 5 ft. 3 in. 2 cinders.
Droylsden -	11,300	38,218	11,250	750,000 gallons.	6 tanks. Total capacity 1,054,080 gallons.	Lime	9 filters. Total area 864 square yards, 868 gallons per square yard.	3 ft. 6 in. rough and fine gravel, polarite and sand.
Failsworth -	14,152	55,870	About 14,000.	Between 380,000 and 500,000 gallons.	2 detritus tanks, 6 upward-flow tanks, and 2 precipitation tanks. Total capacity 677,000 gallons.	Lime and copperas and ferrozone.	6 filters. Total area 960 square yards, 458 gallons per square yard. 1 sprinkler filter, area 329 spuare yards.	Polarite 2ft. 7in., in following material: 7 in. sand, 12 in. sand and polarite mixed, 2 in. sand, 2 in. pea gravel, 2 in. bean gravel, and 6 in. broken stone; sprinkler 9 ft. coke.
Farnworth	27,000	90,000	26,400 (all connected, except 600 Rural).	About 600,000 gallons dry weather flow.	3 tanks, each 160ft. by 50ft. by 9ft.; 2 tanks, each 100ft. by 28ft. by 9ft. Total capacity 1,665,000 gallons.	Very little chemicals now used.	15 filters. Total area 4,300 square yards, 140 gallons per yard.	1ft. 3in. sand and gravel, 2 ft. 6 in. sand and polarite, and 5 ft. cinder beds.

well Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued*.

(9) Method of using Filters whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Intermittent	None	—	Given to farmers.	0	8	8	100	Condensing water and manufacturing refuse equal to the normal flow of sewage is turned into the sewers, but steps are being taken to have the same removed. Plans for extension of the works in course of preparation.
Intermittent	None	—	On land	6	4	10	40	
Intermittent nd as contact beds.	None	—	Air dried and taken by farmers.	4	7	11	64	
Intermittent	None	—	Deposited in tanks or lagoons and allowed to dry.	7	2	9	22	A large amount of copperas escapes from the copperas works into the sewers and acts as a precipitant along with the lime added.
olarite inter-ittent sprinkler continuous.	About 3 acres	—	By running in sludge lagoons and allowing it to dry to enable it to be removed on to land.	9	2	11	18	Plans for further works have been submitted to the Local Government Board.
Intermittent	None	—	Carted away by farmers.	4	5	9	56	

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey

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Urban District Councils—*cont.*								
Golborne (Edge Green). Golborne (Wigan Road).	7,300	30,373	Scheme in hand.					
Gorton - - -	29,500	95,124	29,000	980,000 gallons dry weather flow.	2 catch pits; 6 circular, 2 detritus, and 3 precipitation tanks. Total capacity 1,469,466 gallons.	Alumino ferric	6 filters, 4 roughing filters, storm filter. Total area 4,440 square yards, 220 gallons per square yard.	6 in. sand,12 i sand and p larite mixe 3 in. sand,3 i pea grave 3 in. bea gravel, 12 i broken ston cinders.
Hale - - -	6,200	39,781	About 4,750.	150,000 gallons dry weather flow.	4 small open tanks and 1 covered tank. Total capacity 62,000 gallons.	Alumino ferric	6 filters 240 square yards.	4 ft. clinke cinders (2 in gauge).
Hazel Grove and Bramhall U.D.C. (Bramhall).	7,932	39,682	About 1,500.	About 130,000 gallons.	2 tanks. Total capacity 202,500 gallons.	None	5 filters. Total area 940 square yards.	4 ft. 3 in. screened cinders.
Hazel Grove and Bramhall (Offerton).			About 5,000.	150,000 gallons.	3 tanks. Total capacity 150,000 gallons.	Alumino ferric	2 filters. Total area 377 square yards, 397 gallons per square yard.	4 ft. gravel and ashes.
Heaton Norris	9,856	76,273	8,600	293,000 gallons.	2 tanks. Total capacity 280,000 gallons.	Alumino ferric	4 filters. Total area 870 superficial yards, 470 gallons per square yard calculated on 625 square yards area of primary filters.	1 ft. 9 in. gravel and cinders.
Hindley (Hindley Green).	23,504	86,125	3,500	30,000 gallons.	4 tanks. Total capacity 120,000 gallons.	Alumino ferric	4 filters. Total area 110 square yards, 272 gallons per square yard.	3 ft. 6 in. rough and fine gravel, coke, and sand.
Hindley (Plattbridge).			About 21,000.	250,000 gallons.	2 tanks. Total capacity 500,000 gallons.	Alumino ferric	—	—

rwell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Continuous	None at present	—	Pressed and carted to land adjoining.	2	5	7	71	
Intermittent	9½ acres.	—	Nursery gardener and land.	1	10	11	91	
Intermittent	Area for storm water 3 to 6 dilution = 2,500 square yards. About 5,000 square yards available at present for effluent.	—	On the site	0	2	2	100	
ntermittent	—	—	Carted away by local farmers.	4	7	11	64	
ntermittent	Nil.	—	Removed by farmers.	0	8	8	100	The alteration in filter area will come into use very shortly.
ntermittent	None	—	Given to farmers	0	8	8	100	
ntermittent	About 5 acres	50,000	Carted away by farmers.	0	10	10	100	A scheme for additional works is before the Local Government Board.

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey a

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Council—*cont.*								
Hollingworth -	2,447	11,388	1,600	40,000 gallons.	3 tanks. Total capacity 95,625 gallons.	None	3 filters. Total area 200 square yards.	3 ft. 3 in. sand and cinders.
Hurst - - -	7,193	25,000	—	Sewage treated at the sewage works of Ashton-under-Lyne Corporation.				
Ince - in - Makerfield.	1,628 (Within Watershed.	2,637	—	Sewage treated at the sewage works of the Hindley Urban District Council.				
Irlam - - -	4,750	23,601	3,500	85,000 gallons.	—	—	—	—
Kearsley - -	9,217	27,592	6,600	132,000 gallons.	3 tanks, each 89 ft. by 35 ft. by 5 ft. 9 in. Total capacity 335,811 gallons.	None	6 filters and 2 contact beds. Total area 908 square yards, 145 gallons per square yard.	2 ft. 9 in. of coke and cinders and 3 ft. cinders.
Knutsford - -	5,300	29,508	4,800	214,000 gallons.	3 tanks Total capacity 291,000 gallons.	Alumino ferric	5 filters. Total area 558 square yards, 383 gallons per square yard.	3 high level filters, graduated cinders, 2 ft. 6 in. deep. 2 low level filters, graduated cinders 2 ft. deep and 6 in. of river gravel. Total depth 2 ft. 6 in.
Lees - - -	3,621	17,794	—	Sewage discharged into the sewers of the Oldham Corporation.				
Levenshulme -	11,485	50,428	—	Sewage treated at the farm of the Withington Urban District Council.				
Littleborough -	11,166	52,292	8,800	290,000 gallons.	4 tanks. Total capacity 350,000 gallons.	Alumino ferric	2 filters. Total area 290 square yards, 1,000 gallons per square yard.	2 ft. 6 in., composed of broken stone and cinders or mill ashes.
Little Hulton (Ellenbrook Outfall).	7,294	32,302	5,000	100,000 gallons dry weather flow.	1 septic tank. Capacity 103,500 gallons.	None	3 filters. Total area 2,600 square yards, 38 gallons per square yard.	5 ft. cinders
Little Hulton (Worsley Road).			1,000	20,000 gallons dry weather flow.	1 covered tank. Capacity 20,700 gallons.	None	2 filters. Total area 270 square yards, 74 gallons per square yard.	Cinders 5 ft. deep.
Little Lever -	5,119	16,527	5,000	140,000 gallons.	3 tanks. Total capacity 421,875 gallons.	Lime and copperas.	3 filters. Total area 290 square yards, 482 gallons per square yard.	3 ft. sand, polarite, and gravel.

rwell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters (whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Intermittent	2½ acres	—	Taken by farmers.	0	9	9	100	
—	5 acres in use, planted with willows, under-drained, 5 ft. to 6 ft. deep.	17,000	Sludge is put on the land.	1	7	8	88	
Continuous	Not yet in use	—	Very small quantity of sludge is put on land.	2	6	8	75	
Intermittent	None	—	Dried on spoil bank and given to farmers.	2	8	10	80	
Intermittent	None at present	—	Have at work two sludge presses. The sludge is carted away by farmers.	1	8	9	89	
4 hours in use, 48 hours rest.	—	—	—	0	8	8	100	Additional filter beds for storm water in course of construction at both places in compliance with the demands of the Local Government Board.
ach filter in use 24 hours, then rested 24 hours.	None	—	—	0	8	8	100	
Intermittent	None	—	Partly to farmers and partly on own land.	1	8	9	89	

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey a

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Councils—*cont.*								
Lymm - - -	4,707	20,198	4,707	About 70,000 gallons.	1,000 lineal yards of deeply excavated carriers with weirs giving upwards of 25,000 cubic feet capacity in which the sewage is impounded.	—	—	—
Marple (Estimated).	5,650	32,383	4,288	From 80,000 to 90,000 gallons.	4 tanks. Total capacity 151,875 gallons.	Alumino ferric and ferrozone.	4 filters. Total area 611 square yards; also land filter, 126 yards by 4 yards.	3 ft. 6 in. gravel and cinders.
Milnrow - -	8,400	48,393	7,700	About 192,500 gallons.	3 tanks, each 100 ft. by 30 ft. by 6 ft. Total capacity 337,500 gallons.	Alumino ferric	—	—
Moss Side - -	27,600	127,506	27,600	970,000 gallons dry weather flow.	6 tanks. Total capacity 652,660 gallons.	Alumino ferric	None	—
Mottram - in - Longdendale.	3,128	10,269	About 900	22,500 gallons.	2 tanks. Total capacity 64,800 gallons.	Alumino ferric	2 filters. Total area 96 square yards.	4 ft. 6 in. cinders
New Mills - -	7,773	34,185	6,200	100,000 gallons.	3 tanks	None	3 filters. Total area 72 square yards.	4 ft. deep
Norden - - -	3,907	20,000	1,282	40,000 gallons.	4 tanks. Total capacity 24,793 gallons.	Almunio ferric	1 filter. Total area 75 square yards, 533 gallons per square yard.	3 ft. ashes and gravel.
Prestwich (Clough Works).	12,839	62,661	12,039	600,000 gallons.	9 tanks. Total capacity 606,010 gallons.	—	5 filters. Total area, 1,328 square yards, 451 gallons per square yard.	1 filter, cinders and stone; 4 filters, cinders 3 ft. deep.
Prestwich (George Street Works).				3,500 gallons	1 tank. Total capacity 10,500 gallons.	None	2 filters	2 ft. 6 in. of fine cinders.

rwell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters (whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
—	15 acres planted with willows.	4,666	Periodically cleaned out of carriers and used as top dressing.	0	8	8	100	
Intermittent	—	—	Disposed of on farm land near sewage works.	1	9	10	90	
—	7½ acres	25,666	On land	1	8	9	89	Artificial filters in course of construction.
—	27 acres	35,925	Pressed and given to farmers.	3	5	8	63	11 a. 1 r. 29 p. of land recently purchased for extending the farm works for disposal of storm water under consideration. Application for reconstruction of storm water sewer before Local Government Board.
Intermittent	2½ acres	—	—	0	7	7	100	
ntermittent nd Continuous.	5½ acres	—	Given to farmers	0	8	8	100	
Continuous	None	—	On land	4	2	6	33	New outfall works in course of construction.
ntinuous and ntermittent.	8 acres	—	Given to farmers	5	3	8	38	
ntermittent	None	—	None	8	1	9	11	

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey a

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Council—*cont.*								
Radcliffe - -	25,368	100,882	22,850	1,100,000 gallons.	8 tanks. Total capacity 1,056,000 gallons.	Alumino ferric	16 filters. Total area 2,000 square yards, 550 gallons per square yard.	250 square yards, containing 9 in. of polarite and 2 ft. 4 in. of gravel and sand; 1,750 square yards, containing 9in. of cinders and 2 ft. 4 in. of gravel and sand.
Ramsbottom -	15,920	68,316	14,245	500,000 gallons (when completed).	6 settling tanks (under reconstruction).	None	4 filters. Total area 950 square yards.	9 feet of coke breeze.
Royton - - -	14,881	64,014	11,500	About 520,000 gallons.	6 tanks. Total capacity 543,240 gallons.	Alumino ferric	8 filters. Total area 800 square yards.	6 polarite filters, 3 ft. deep, viz.:— 9 in. Lowestoft Sand, 9 in. polarite and sand, 3in. coarse sand, 15 in. gravel in sizes graduated from pea gravel to size of walnut; 36 rows of 4-in. drain tiles 18 in. apart at bottom of filters, and 2 clinker filters each 3 ft. deep.
Sale - - - -	12,088	81,708	12,088	750,000 gallons dry weather flow.	10 tanks. Total capacity 2,106,561 gallons.	Ferric per salt of iron.	12 filters. Total area 3,955 square yards (not yet complete).	3ft. polarite and sand.
Stretford - -	34,060	249,399	10,600	About 700,000 gallons dry weather flow	—	—	—	—

well Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters (whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Intermittent	1 acre	—	Pressed into sludge cake and given to farmers.	1	9	10	90	5 acres of land in preparation.
Continuous	About 10 acres	—	—	—	—	—	—	Reconstruction of septic tanks and sludge filters, and formation of land filtration plots almost completed.
Intermittent	8 land filter plots. Total area about 5 acres.	—	Given to farmers for use as manure.	0	8	8	100	
—	None	—	Given to farmers.	0	4	4	100	
—	51 acres	13,725	Pumped on to the land from receiving tank.	0	8	8	100	The remainder of the township is connected to the Manchester system.

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Councils—*cont.*								
Swinton and Pendlebury (Swinton) -	27,001	104,000	About 20,000	640,000 gallons dry weather flow	9 tanks. Total capacity 938,820 gallons.	Lime and copperas.	Storm Filters:—Land and cinder filters 7,305 square yards; 14,800 square yards land and cinder filters, 1 foot 6 inches deep cinders; coke filter 350 square yards; cinder filters 2,640 square yards, depth 3 ft. 6 in. Total area 25,095 square yards.	Bacteria Beds —10 first contact, 9 second contact, each 75ft. by 75ft. by 3 ft. 3 in. average depth graded clinkers
Swinton and Pendlebury (Pendlebury)			About 7,000	About 160,000 gallons dry weather flow	3 tanks. Total capacity 413,550 gallons.	Alumino ferric	Polarite, 150 square yards, land and cinder filters 3,344 square yards, and 250 square yards cinder filters. Total area 3,744 square yards, 42 gallons per square yard.	Polarite 3 ft., land and cinders 3 ft. 6 in.
Tottington -	6,300	24,567	2,000	20,000 gallons.	2 tanks. Total capacity 120,000 gallons.	Alumino ferric	—	—
Turton (Belmont)	12,355	73,219	720	38,000 gallons.	3 tanks. Total capacity 21,469 gallons	None (Septic)	1 filter. Total area 220 square yards	Cinders 3ft. deep
Turton (Bradshaw Works)			3,375	140,000 gallons dry weather flow.	4 tanks. Total capacity 367,300 gallons	Alumino ferric	None	Sand & gravel (land filters).
Turton (Eagley Works)			5,080	195,000 gallons dry weather flow.	3 tanks. Total capacity 195,000 gallons	Lime & copperas	2 filters. Total area 182 square yards, 1,071 gallons per square yard.	Fine furnace ashes 1ft. 9in. and broken ballast 1ft. 9in. Total 3ft. 6in.

rwell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters (whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
—	6 acres	—	Used for farming purposes.	9	2	11	18	
Intermittent	None	—	Sludge pressed and removed by farmer.	5	4	9	44	Application is being made to the Local Government Board for powers to borrow for extension of filtration area.
—	2 acres	10,000	Deposited on remaining 4 acres of land. Total amount of land for filtration or irrigation 6 acres, but at present only 2 acres are used.	0	9	9	100	
Continuous	484 square yds.	—	Deposited on land; no sludge from tanks, only from the screens.	1	2	3	67	
Intermittent	$2\frac{3}{4}$ acres in 5 filtration areas.	50,909	Taken by farmers.	0	7	7	100	
Intermittent	None	—	Taken by farmers.	2	6	8	75	

Particulars as to the methods of sewage treatment adopted by the Local Authorities in the Mersey a

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population Connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Councils—*cont.*								
Tyldesley (with Shakerley)	14,843	75,950	14,663 1,300 Astley sewage treated by Tyldesley.	480,000 gallons.	2 tanks subdivided into 32.	Ferrozone & lime	8 filters. Total area 500 square yards.	Cinders 3ft. de
Urmston and Flixton District Drainage Joint Committee	11,100	57,558	10,500	210,000 gallons dry weather flow.	2 Septic tanks. Total capacity 204,000 gallons.	None	3 filters. Total area 3,700 square yards.	5 ft. fine cinder
Wardle (Higher Works)	4,426	15,782	1,500	30,000 gallons.	1 circular tank. Total capacity 32,000 gallons.	Alumino ferric	3 filters. Total area about 105 square yards, 285 gallons per square yard (1 new circular filter bed with cinders. Patent intermittent sprinklers).	3 ft. deep ashes, circular filte bed 6 ft. dee clinkers.
Wardle (Lower Works)			2,500	50,000 gallons.	1 circular tank and 4 square tanks. Total capacity 50,000 gallons.	Alumino ferric	4 filters—2 high level (each 100 square yards) and 2 low level (each 140 square yards). Total area about 480 square yards, 104 gallons per square yard. High level effluent treated by second contact on low level filter.	High level, coarse clinke 3ft. deep. Low level, coarse clinke 2ft. deep and 1ft. fine ashes on top. 24 hours contin uous filtration and 24 hours rest.
Westhoughton (Dog Holes)	14,377	54,000	About 1,000	About 10,000 gallons.	—	—	—	—
Westhoughton (Marsh Brook)			About 1,000	About 15,000 gallons.	—	—	—	—
Westhoughton (Roger's Farm)			About 11,500	About 220,000 gallons.	2 tanks. Total capacity 450,000 gallons.	Copperas, manganese liquor, and lime.	2 filters. Total area 1,000 square yards. A third filter in course of construction.	About 3 ft. deep. Material: Common engine ashes, screened, the coarse ashes being placed in the bottom layers and the fine in the top.

well Watershed, derived from information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of using Filters whether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
Intermittent	80 acres	—	Pressed and then used on land as manure.	5	5	10	50	
24 hours in use, 24 hours rest.	9 acres	—	Removed by farmers.	0	8	8	100	
Intermittent	—	—	Collected on sludge filter beds, and when solid wheeled on land.	4	5	9	56	
Intermittent	—	—	—	2	6	8	75	
—	15 acres	666	Whole of sewage irrigated on land.	0	1	1	100	
—	10 acres	1,500	Whole of sewage irrigated on land.	1	6	7	86	
Intermittent	About 50 acres available.	—	Carted on the land.	0	9	9	100	The filters have been constructed in consequence of the land being clay, and unsuitable for filtration.

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey an

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Urban District Councils—*cont.*								
Whitefield -	6,775	22,075	5,000	Average 450,000 gallons per day.	10 tanks. Total capacity 140,000 gallons.	Alumino ferric	—	—
Whitworth -	9,578	30,964	About 7,000.	231,000 gallons.	3 tanks Total capacity 226,875 gallons.	Alumino ferric	13 filters. Total area 972 square yards.	4 filters, 3 ft. sand and gravel; 9 filters, 3 ft. coarse and screened ashes.
Wilmslow (Northern Works).	7,361	47,874	3,000	78,000 gallons.	2 tanks. Total capacity 89,400 gallons.	Alumino ferric	—	—
Wilmslow (Southern Works).			3,500	90,000 gallons.	—	—	—	—
Withington (includes Levenshulme).	52,000	320,000	51,000	About 2¾ million gallons (half subsoil water).	—	—	—	—
Worsley (Barton Old Hall).	12,462	64,119	9,777	300,000 gallons.	10 tanks. Total capacity 58,000 gallons.	—	—	—
Worsley (Boothstown).			1,650	50,000 gallons.	2 tanks. Total capacity 26,000 gallons.	Lime and alu-mino ferric.	—	—
Yeardsley-cum-Whaley.	1,487	7,692	No scheme.					
Rural District Councils—								
Barton (Clifton).	2,947	39,436	1,920	38,400 gallons dry weather flow.	1 tank. Total capacity 4,800 gallons.	None	Total area 1,600 square yards, 24 gallons per square yard.	Sand and ashes
Barton (Davyhulme).	1,250	15,757	100	2,000	2 screening tanks. Total capacity 573 gallons.	—	Total area 106 square yards, 18 gallons per square yard.	Sand and ashes, 2 ft.
Bucklow (Dunham Massey).	19,885	185,193	450 Remainder flows through Altrincham U.D.C.	—	2 tanks. Total capacity 14,400 gallons.	None	—	—
Bucklow (Northenden).			1,500	45,000 gallons.	2 screening tanks. Total capacity 13,500 gallons.	None	—	—
Bucklow (Timperley).			2,500	75,000 gallons.	3 tanks. Total capacity 44,000 gallons.	None	3 cinder filters, 763 square yards.	3½ ft. cinders

ell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of sing Filters hether Intermittent or ontinuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
—	3½ acres	130,000	Carted away by farmer on the land.	6	4	10	40	
ntermittent	3½ acres	—	Pressed	0	7	7	100	
—	7 acres	11,142	Used by farmers.	2	9	11	82	
—	8 acres	11,250	Whole of sewage irrigated on land.	1	10	11	91	
—	49 acres	—	Silt used as manure upon land. Sludge pressed and burnt in destructor.	7	5	12	42	New works recently completed for treatment by sedimentation and filtration on 12 acres of bacteria beds, with 2½ acres for storm water
—	44 acres	6,818	Used as manure upon land.	8	1	9	11	New scheme now being prepared for Barton.
—	4 acres	12,500	Used as manure upon land.	1	8	9	89	
hours work- ng, 48 hours st.	—	—	Removed by farmers.	0	9	9	100	
—	—	—	Removed by farmers.	5	3	8	38	
—	3½ acres	3,857	Dried on land and given to farmers of same farm.	1	5	6	83	Rate of filtration calculated on basis of 30 gallons per head per day.
—	4½ acres	10,000	Dried and carted away by farmers.	3	6	9	67	
termittent	2½ acres	—	Dried and given to adjoining farmer.	0	10	10	100	

Particulars as to the Methods of Sewage Treatment adopted by the Local Authorities in the Mersey

Name of Authority.	(1) Population.	(2) Rateable Value.	(3) Population connected up.	(4) Estimated Quantity of Sewage in 24 hours.	(5) Number of Precipitation Tanks and Total Capacity.	(6) Precipitant used.	(7) Number of Filters and Total Area.	(8) Depth and Character of Filtering Material.
Rural District Councils—*cont.*								
Bury (Hollins)	1,700	52,135 (R.D.C. District)	1,050	—	—	—	—	—
Bury (Prestolee).	1,000		600	6,000 gallons dry weather flow.	Septic tanks, 13,000 gallons.	None	3 filters. Total area 220 square yards, 27 gallons per square yard.	5 ft. cinders
Chapel-en-le-Frith.	13,328	107,407	2,500	55,000 gallons	3 tanks in each series worked in duplicate, 100,000 gallons in each series. Total capacity, 200,000 gallons.	Alumino ferric	—	—
Disley	2,900	13,450	1,650	25,000 gallons	3 tanks. Total capacity, 54,562 gallons.	Ferrozone	None	—
Hayfield (Parish of Hayfield).	2,641	13,170	1,410	21,000 gallons	2 tanks. Total capacity 42,000 gallons.	Alumino ferric	None	—
Leigh (Glazebury Works).	5,258 (Portion of R.D.C.	31,505 District)	About 700	—	One settling tank.	—	1 filter	Cinders
Leigh (Lowton Common Works).			About 800	Works consist of a filter bed. A second bed in course of construction.		(See note to Lowton St. Mary's Works as t		
Leigh (Lowton St. Mary's Works).			1,000	The works consist of a tank and filter bed, which have been constructed in dealt with, for previous to such sewerage arriving at the works it passe stream are quite dry.				
Limehurst (Bardsley).	10,338	35,829	1,800	45,000 gallons	3 tanks. Total capacity 60,555 gallons.	Alumino ferric	3 coarse contact beds, 3 fine contact beds, 435 square yards.	3 ft. clinker and ashes.
Limehurst (Crossbank).			About 500	12,500 gallons	2 tanks. Total capacity 27,000 gallons.	None	4 filters, 213 square yards.	3 ft. furnace clinkers.
Limehurst (Waterloo). A portion of Limehurst R.D.C. included in Ashton-under-Lyne Corporation Scheme.			About 2,800.	70,000 gallons	5 tanks. Total capacity 112,000 gallons.	Alumino ferric	3 coarse contact beds, 4 fine contact beds, and 2 small contact beds. Total area 772 square yards.	3 ft. clinker and ashes.
Ludworth and Mellor Joint Sewerage Board.	—	—	3,000	45,000 gallons	1 septic tank. Capacity 67,500 gallons.	None	6 bacteria beds. Total area 800 square yards.	3 ft. deep, screened coke and furnace slag (not ashes) rejected by 1½ in. mesh and passed by 4 in. mesh.
Macclesfield (Poynton).	2,544 (Portion of R.D.C.	16,182 District).	2,225	38,000 gallons dry weather flow.	2 tanks. Total capacity 61,875 gallons.	Alumino ferric	None	—
Tintwistle	2,095	22,219	No scheme.					

ATERSHED—*continued.*

ell Watershed, derived from Information supplied by the Authorities to the Joint Committee—*continued.*

(9) Method of sing Filters hether Intermittent or Continuous).	(10) Area of Land used for Filtration or Irrigation.	(11) Rate of Filtration in Gallons per Acre.	(12) Sludge: How disposed of.	(13) Number of Samples Above Limit.	(14) Number of Samples Below Limit.	(15) Total Samples.	(16) Percentage of Samples Below Limit.	(17) Remarks.
—	About 5 acres							
hours work nd 48 hours est each bed.	None	—	None	0	8	8	100	
—	4 acres	13,750	—	1	8	9	89	
—	2 acres	12,500	Dried and given to adjoining farmer.	0	7	7	100	
—	7,436 square yards.	13,700	—	0	6	6	100	
ontinuous	—	—	—	1	1	2	50	
ntity of sewage.)		—	—	2	0	2	0	
bed of a small stream. It is impossible to say what sewerage is g about 4 miles of open ditches. In summer the ditches and								
termittent	About 1 acre	About 40,000 gallons per acre.	Air dried and given away.					
termittent.	About 1 acre	12,500 gallons daily sewage flow for 1 acre of land.	Air dried and given away.					
termittent.	2,800 square yards.	About 60,000 gallons per acre of filters, &c.	Air dried and given away.					
ermittent, 1 our to fill, 2 ours contact, hour to pty, and 4 ours standg.	3 acres, 3 roods	—	None to dispose of as yet.					
—	5½ acres	6,900	Removed by Farmers.	1	5	6	83	

Carlisle and the River Eden.

The river Eden from the neighbourhood of Carlisle to its estuary, a distance of about 7 miles, was examined by the authors on August 2nd and 3rd, 1904. Mr. Slater, clerk to the Fisheries Board very kindly accompanied them, and rendered them valuable assistance by his intimate knowledge of the river. The proprietor of the fishing, Mr. T. Robinson, also gave them material assistance in examining the non-tidal portion of the river immediately below Carlisle, by providing boats and men for the purpose.

The weather at the time was very warm and dry, and the authors were informed by the fisheries inspector that the river was lower than it had been for several years previously; notwithstanding this, it was still a broad and rapid stream, and its waters just above Carlisle were clear and evidently free from anything like serious pollution. They were found to contain 7·05 c.c. oxygen per litre, which is the saturation quantity for distilled water at 16°C.

The appearance of the river and of its waters at this point, in fact, fully supported the reputation which it has so long enjoyed for the quality and abundance of its trout, salmon and various other kind of fish. But a little lower down, about three-quarters of a mile below Carlisle, its appearance was grievously marred by the sewage which was being emitted from an outfall on the left bank of the river. Through this outfall was flowing the sewage of Carlisle in a crude state. The population of Carlisle is about 45,000.

The outfall pipe was evidently constructed to deliver the sewage below the surface of the water, but at this time it appeared to be choked and the sewage was bursting out from a concrete channel on the bank and was cascading into the river. Just at the outfall, the flow of the river water was very rapid, and the effect of this was to keep the sewage pressed towards the left bank for a distance of 500 or 600 yards, giving the waters affected by it a foul appearance, and polluting the bed underneath them to a serious extent by the deposition of sewage solid matters along it; the waters towards the right bank for the distance stated seemed scarcely to be affected by the sewage.

This reach of the river is followed by rapids which continue for about 150 yards, and the waters and sewage during their course through it became thoroughly intermixed. The dissolved oxygen in the waters here amounted to—Surface, 6·48 c.c. oxygen per litre; bottom, 6·19 cc. oxygen per litre. After this the river deepens considerably, and the flow of the water becomes sluggish, and here for a distance of about 2 miles, the river acts as an excellent subsidence tank, with the result that its bed was covered with solid sewage matters, and presented a foul and disgusting appearance. Mr. Robinson's men demonstrated the injury being done to the bed of the river at this point by shooting a salmon net across it. When the net was landed it was found to be clogged with a mass of crude sewage matters. Quite a large heap of similar material at the place where the net was dragged (Grinsdale Island) was a silent witness to what the net had picked up on previous occasions. Quantities at times getting inflated with gases rise to the surface and float with the stream. At the time of the authors' visit, this debris was not exactly stinking, but they were told that the smell is at times disgusting, and that the fishermen sometimes vomit from it. Black offensive sludge lined the bank of the river at this part at least a foot thick.

The waters also along this portion of the river appeared to be dirty, especially the slack portion along the bank. Both bottom and surface waters were, however, well aerated, thus—a sample collected 7 feet below surface contained 5·91 c.c. oxygen per litre; a surface sample contained 6·33 c.c. oxygen per litre. It is important to note that the deposited solid matters remain quiescent on the bed of this portion except at freshets, and that they in consequence exercise little de-aerating effect in the gently flowing waters above them. Compare the aeration of these waters with that of the waters of the Ouse, Liffey and Thames.*

Lower down, the river again narrows into rapids, and about 2 miles down stream the waters were again apparently free from pollution; and fish, especially the kind locally known as "herling," became abundant. Samples of water collected from the stream showed an aeration as follows :—

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* pp. 88–91 332.

Surface - -	5·97 c.c. oxygen per litre, temp. 18·8 C.
Bottom - -	5·34 c c. oxygen per litre.

The river rapidly broadens out below Rockcliff, and wide sand banks are exposed. These were for the greater part quite clean, but the bank is being cut away, leaving mud at the margin along Burgh marsh and Drumsburgh marsh. Abreast of Sandsfield, about 1¼ miles below Rockcliff, a surface sample was collected, and examined with the following results :—

Chlorine - - -	2·16 gms. per litre.
Oxygen - - -	5·82 c.c. per litre, temp. 19·3 C.

The average tides run about 2 miles above Rockcliff, that is within about 2½ miles of the Carlisle Outfall.

Fish.

The authors were informed that course fish are abundant about three-quarters of a mile below the outfall. All the fishery people were agreed that salmon would not run up from the sea except after a freshet, and it was also stated that salmon below the outfall had a distinct taste. The authors themselves had some experience of this. They were presented with some herling by a gentleman from his catch. The fish weighed about ½ to ¾ lb., and were extremely nice looking fish. The flesh of the fish was similar to that of trout, but had an unpleasant earthy taste. The taste was so suggestive of humus matters that it was difficult to avoid the conclusion that it was due to the pollution of the river, especially by solid matters as above described.*

Vegetation.

Plenty of green algae and a long green weed with white flowers, locally known as "eel grass," were observed in the river. Very little seaweed was, however, visible along Burgh and Drumsburgh marshes, probably owing to the rapid tides and moving sand. But near Drumsburgh, one spot which was protected from the tide by a groin was abundant in ulva and some enteromorpha. Both weeds were fairly abundant at the small creeks.

Conclusions.

If the waters of the river Eden below the Carlisle outfall be included in the third class of tidal waters, the pollution by the *liquid* matters from the outfall must be regarded as less than the maximum amount allowable under the standard proposed for that class of water ; the aeration tests which have been given above prove this ; but the pollution by *solid* matters is not allowable under the standard, and so the discharge from the outfall must be condemned because the solid matters were not previously separated. If they were, there can be no doubt that the liquid portions of the sewage could be continued to be discharged without danger to public health or to fish life.

Plymouth and the Estuaries of the Tamar and of the Plym.

The confluence of the estuaries of the Tamar and Plym forms the Plymouth Sound, and on reference to the Ordnance map, it will be readily understood that the waters of these estuaries and of the neighbouring inlets present excellent means of studying the effect of the discharge of crude sewage into tidal waters, the currents of which vary in depth, strength and direction.

The Sound is three miles long from north to south, and 2½ to 3 miles broad. Its inlets on the north side from the east end westwards are—(1) Catwater, (2) Sutton pool, 90 feet wide at entrance and 27 acres in area, (3) Millbay Cove, (4) Stonehouse pool, and (5) Hamoaze, 4 miles long from Mount Edgcumbe to Saltash.

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* See the formation of humus matters from sewage solids, Section 1, p. 32.

The great breakwater stretches across the middle of the Sound $2\frac{1}{2}$ miles south of the Hoe. It is 360 feet wide at base, sloping to 45 feet at top, and 1,700 yards long. The open channel at either end of the breakwater is 4,300 feet wide on the west and 2,200 feet wide on the east.

Plymouth, Stonehouse, and Devonport are situated close together along the northern shore of the Sound. There are also Saltash on the right bank of the Tamar, and Torpoint a little to the south of it on the Hamoaze. The populations of these places are:—

Plymouth	114,003	Saltash	7,928
Stonehouse	15,111	Torpoint	2,000
Devonport	75,334		
	204,448		9,928

The authors were informed during their visit to these localities on August 16th and 17th, 1904, that sewage was being discharged in the crude state from the following outfalls:—

1. Laira Outfall (Plymouth).
2. Deadman's Bay Outfall (Plymouth).
3. Fisher's Nose Outfall (Plymouth).
4. Millbay Outfall (Plymouth).
5. Firestone Bay Outfall (Stonehouse).
6. Mutton Cove Outfall (Devonport).
7. Moon Cove Outfall (Devonport).
8. North Corner Outfall (Devonport).
9. Bull Point Outfall (Devonport).
10. Saltash Outfall.
11. Torpoint Outfall.
12. Millbrook Outfall.

Of the four outfalls from Plymouth, one only, that at Fisher's Nose, which discharges 90 yards from the shore into 30 feet below low water at spring tides, was suitably situated. On reference to the Appendix of this Report, p. 76, it will be found that nuisance has been caused from the deposit of sewage on the foreshore in Deadman's Bay, and an annoyance at Millbay, and that the outfalls causing these nuisances will be dispensed with, the sewage being discharged by the new main drainage system into deep water about 95 feet below low water.

Where the sewage discharges at the Fisher's Nose, that is into the Sound at the mouth of Catwater, no annoyance has been caused. At this point, and at that of the new outfall, the tidal currents are rapid. The first has west-south-westerly direction, and the second an easterly direction. After joining together, both take a south-easterly direction to the sea by the eastern end of the Plymouth Breakwater.

On reference to p. 37 of the Appendix to this Report, it will be seen that one of the Devonport outfalls discharges a clear effluent free from smell. Of the other three, two discharge along the shore. It is stated that the discharge from these outfalls has ruined a bathing place close by, by discolouring the water and causing accumulations of waste paper, etc.

The authors made an examination of the waters in the neighbourhood of Plymouth and Devonport on the dates above mentioned, and came to the conclusion that the solid sewage matters were the real offenders in giving rise to nuisance. The discoloration caused by the discharge of sewage into slack waters was also a cause of serious trouble, but they did not find that the aeration of the tidal waters was reduced below the minimum limit allowable for the protection of fish life. Thus the salinity and aeration of samples collected from the surface waters of the Plym about 300 yards above and below the Laira outfall, during the fifth hour of the ebb of an average, was as follows:—

Sample above outfall—Salinity = 11·7 parts chlorine per litre.
Aeration = 5·71 c.c. oxygen per litre.

Sample below outfall—Salinity = 12·4 parts chlorine per litre.
Aeration = 5 63 c.c. oxygen per litre.

The right bank of the Plym, about 400 yards below the Laira outfall, was covered with mud, which was brown grey on the surface and foul and black immediately below it.

The sewage which was being discharged from the outfall in Deadman's Bay gave the waters a very dirty appearance for a radius of about 80 yards from the outfall at slack tide, but the effluent was lost sight of beyond this.

The waters in the neighbourhood of the outfall at Millbay Cove were also badly discoloured, a sample collected about 350 yards to the south-west of the outfall at slack tide gave the following results:—

Salinity = 20 parts chlorine per litre.
Aeration = 5·85 c.c. oxygen per litre.

A sample of polluted water was collected next day, at low water, vertically over the Millbay outfall, and examined with the following results:—

Salinity = 14·46 chlorine per litre.
Aeration = 4·86 c.c. oxygen per litre.

The outfall pipe was 10 feet below the surface and the sewage was boiling up. No solid excrement to speak of was noticed, but the surface waters were much discoloured. Much rain amounting to 1·06 inches had fallen the previous night.

The salinity and aeration of a sample of water collected from the Tamar near the mouth of the Tavy, on the beginning of the flood tide, were found to be as follows:—

Salinity = 11·7 parts chloride per litre.
Aeration = 6·06 cc. oxygen per litre.

Higher up the Tamar patches of green weed were noticed on the mud of Camel's Head Creek. The banks on the east side at Bull Point were clean to the Suspension Bridge and apparently so further up. At Saltash the green weed seemed to be confined to enteromorpha. Ulva was not seen.

Conclusions.

The Plym, much the smaller of the two rivers, undoubtedly showed signs of being polluted from the Laira outfall to at least the railway bridge. But as deep water was reached these signs disappeared.

The banks of the Tamar showed some pollution, but the volumes of water entering and flowing out of this estuary is so large that other signs of pollution would scarcely be visible.

Mr. Alderman James, a member of the Devon Sea Fisheries Committee, was of the opinion that salmon and peel were not affected by the sewage from Plymouth and from the neighbouring townships, but that they had been seriously affected by mine refuse, containing copper and arsenic. Dead fish had been frequently observed in the river into which the refuse had been discharged. The river had been subsequently improved, and plenty of fish were said to be in it. Several peel had been recently taken in mackerel nets near the Plymouth outfall at West Hoe.

The nuisance complained of in the neighbourhood of several of the above outfalls was chiefly due to sewage solid matters, but it was partly due to discoloration of the tidal waters by the liquid sewage matters. The remedy for both these sources of nuisance appeared to be either to select more suitable positions for the outfall, as the Plymouth authorities were preparing to do, or to purify the sewage before discharge into tidal waters.

It will be observed that the tidal waters in the neighbourhood of the deep water outfall at Fisher's Nose may be included in the first class of tidal waters.

The authors have to acknowledge their indebtedness to the authorities of Plymouth for the use of a steam launch, and to Mr. H. Victor Prigg, the engineer in charge of Mr. Mansergh's main drainage system, which was in course of construction, for kindly acting as their guide, and giving them the benefit of his intimate knowledge of Plymouth and of its neighbouring waters.

River Thames.

The results of analysis of a number of samples of polluted water, which were collected by the authors along the Thames in August, 1904, from abreast of North Woolwich to Chapman Lighthouse, have already been recorded and discussed.*

The results showed that the waters, both surface and bottom, of the Thames, and at all states of the tide, were largely de-aerated, from North Woolwich to beyond Grays. At Mucking the aeration of both surface and bottom waters, especially the latter, began to show a distinct rise. At this point it was at the minimum limit adopted in Section 1 as possible for the continued support of fish life. From it down stream the aeration steadily improved, and at Chapman it amounted to 4·5 c.c. oxygen per litre, and the salinity to 16·4 parts chlorine per litre, practically for both surface and bottom samples, the figures for the latter being slightly higher than those for the former sample.

Reasons are given in Section 1† for regarding the greater portion of the de-aeration of the most polluted portions of the river waters as due to the presence of easily oxidisable substances, possibly products of putrefaction among the suspended matters in the water, originating from the sewage solids deposited from time to time along the bed of the river, and stirred up by the force of the tidal currents.‡

It is interesting to compare these results with the conclusions which Dr. Houston has drawn from the bacteriological examination which he made of the Thames waters, as to their condition at corresponding points along the river.** It will be seen from the following comparative statement that they are in complete agreement:—

Dr. Houston's Conclusions.	Dissolved Oxygen. c.c. per litre.
The bacteriological condition of the River Thames at Barking, Crossness, and Purfleet is very unsatisfactory - - - - - - - - - -	1·44 to 1·55.
At Grays, about five miles lower down the river than Crossness, the water showed some slight evidence of improvement, particularly as regards the B. coli test - - - - - - - - - - - - - -	1·8
At Mucking, 10 miles below Grays, the Thames water shows definite signs of improvement. With regard to coli-like microbes, 11·5 per cent. of the samples contained 100, 57·7 per cent. contained 10, and 30·8 per cent. contained 1 per c.c. As regards B. enteritidis sporogenes, about one-third of the samples contained 10 spores, and about two-thirds 1 spore, per c c. -	3·5 (surface) 4·4 (bottom).
At the Chapman Lighthouse, five miles below Mucking, the Thames water was so far improved relatively as seeming to vie in biological purity (qua B. coli) with some of the samples of filtered London water; about half the samples contained less than one coli like microbe per c.c. As regards the B. enteritidis sporogenes test about four-fifths of the samples from this section of the river gave a positive result with 10 c.c., but a negative result with 1 c.c.	4·4 (surface) 4·6 (bottom).

The acknowledgment of the authors is due to Dr. Williams, M.O.H. to the Port of London, for his courtesy in providing them with means of making their examination of the river, and to Dr. Willoughby, one of the assistant medical officers, for accompanying them and affording them much valuable assistance.

W. E. Adeney,
Royal University, Dublin.

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* Section 1, Table 37. † *Ibid*, p. 91.

‡ See also Section on the River Humber and its Tributaries, p. 332.

**Fourth Report of the Royal Commission on Sewage Disposal, Reports by Dr. Houston on Bacteriological Investigations, Vol. 3, p. 66.

SECTION 7I.

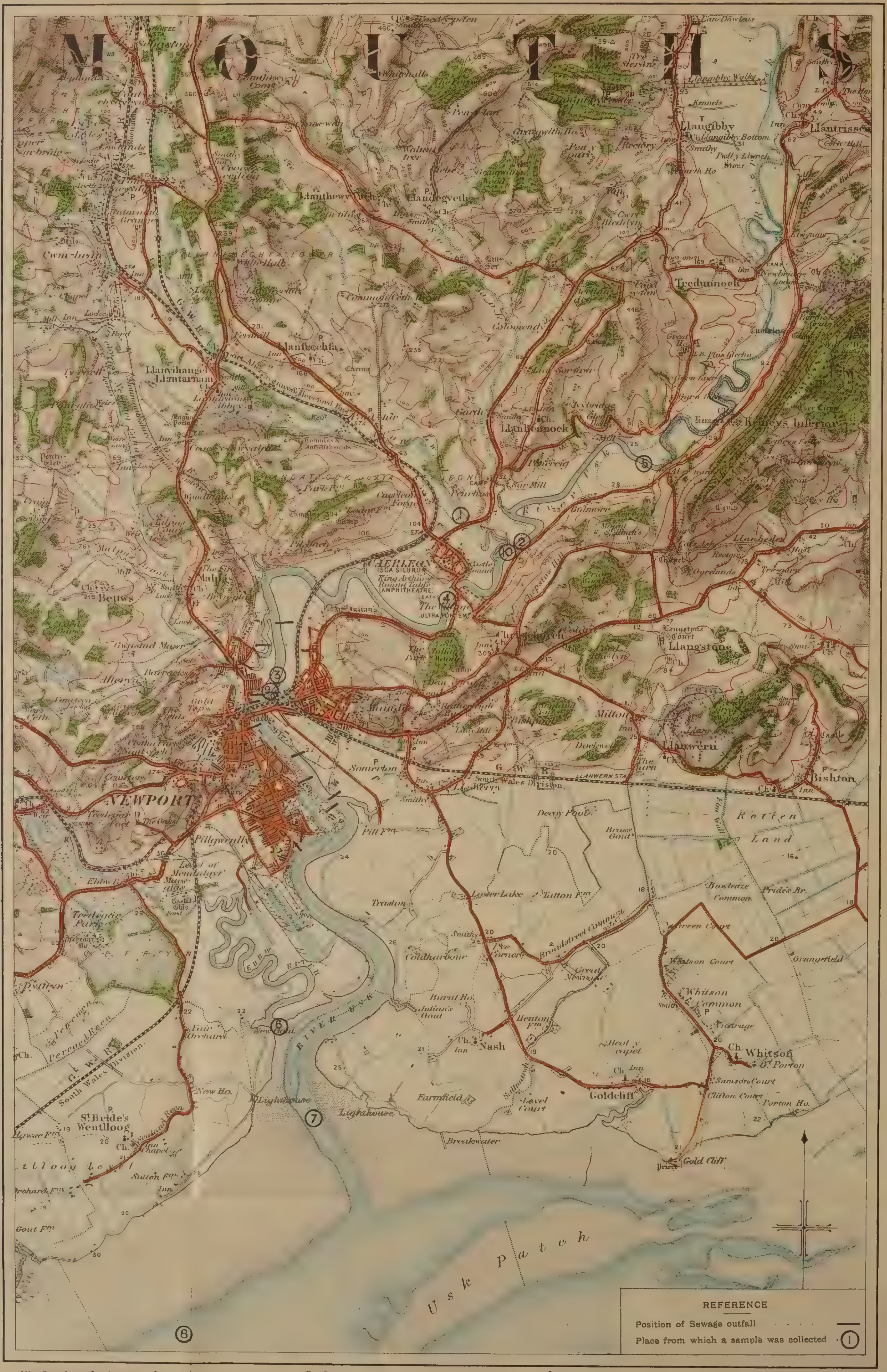
EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

NEWPORT (MON.) AND THE RIVER USK.

NEWPORT & THE USK

ORDNANCE SURVEY OF ENGLAND AND WALES

PARTS OF SHEETS {249. 250.
263. 264.



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Scale of One Inch to One Statute Mile — $\frac{1}{63360}$

Printed at the Ordnance Survey Office, Southampton in 1906

NEWPORT (MON.) AND THE RIVER USK.

The river Usk rises near the eastern boundary of Carmarthenshire, and after traversing the county of Breconshire from west to east, passes into Monmouthshire and eventually enters the estuary of the Severn a few miles below the town of Newport. The total length of the river is about 72 miles of which 16 miles are tidal.

The chief sources of pollution appear to be (1) the sewage from the town of Brecon (population 5,875); (2) the waters of the Afon Llywd; (3) the sewage of Newport; (4) the waters of the Ebbw river.

Regarding the first of these, the pollution is probably not of an extensive character, although in the Report of the Royal Commission on Salmon Fisheries it was returned as rendering the river water partially unfit for salmon, but it was also stated that the matter was being dealt with by the Brecon Town Council, who were carrying out an extensive alteration to their sewage filtration system.

"The Afon Llywd, one of the main tributaries of the Usk, which joins the river at Caerleon, and which has various tinplate and other works and collieries on its banks, is little better than a huge sewer. No attempt is made by the various urban and district councils to deal with the sewage, which flows into the river. Most of the works make some attempt to filter or otherwise reduce the acid coming from the works, and the owners of collieries also to a certain extent reduce the large amount of coal washings which used to flow direct into the river." *

Regarding the third and chief source of pollution. The town of Newport has a population of 70,217, and the total dry weather flow of the sewage is estimated at 2,000,000 gallons per day of twenty-four hours. This sewage is largely domestic, but also includes the effluents from iron works, chemical, manure and rubber works. It is discharged in a crude state into the Usk through several outfalls situated on the river banks. These outfalls are tide-locked during certain hours; the time during which this occurs depending on the nature of the tides, whether springs or neaps. Sewage, therefore, makes its way into the river during both the flood and ebb tides.

The width of the river at Newport is about 1,000 feet and the tidal rise and fall amounts to over 38 feet at springs. The tidal currents are very rapid in the river, varying from four to six knots per hour. Very extensive dilution of the sewage therefore occurs, and the river bed is continually submitted to considerable scouring action. Moreover, this bed gets a thorough exposure to the atmosphere twice in the twenty-four hours. It may be added that the Usk in its tidal reaches is a remarkably muddy stream, the banks on either side consisting of this material to a considerable depth (some feet), while the water is extraordinarily turbid, a tumblerful collected in midstream some miles above Newport depositing sediment to such an extent that its height was at least one-tenth that of the water.

Regarding the Ebbw. "The river Ebbw is in an almost identical position with the Afon Llywd, except that it does not flow into the river Usk, but discharges into the Bristol Channel." †

The Ebbw is in an even worse condition so far as pollution is concerned than the Afon Llywd.*

The Usk in Relation to Fish Life.

The Usk is an excellent salmon river as is apparent from the fact that the average number caught yearly in its upper waters by rod and line amounted to 1,600, while in 1891 (an exceptionally good year, however) no less than 5,000 were taken in that way. Considerable numbers of salmon are also captured by nets, and outside the mouth of the river by curious basket-like contrivances of wickerwork termed "Putts," or "Putchers," but we have not been able to ascertain how many are thus taken yearly.

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* Royal Commission Salmon Fisheries Report, Part III. Appendix. Section 1, p. 182.

† This is scarcely correct as will be seen from the map of the district.

The pollution of the river is of importance chiefly in relation to the salmon fishery, nd we have not been able to ascertain that it affects the condition of the water in any other way or has led to complaint.

Regarding its effects on fish life we may quote the following evidence given before the Royal Commission on Salmon Fisheries in 1900.

Omitting any discussion of the effects of the sewage of the towns of Brecon and Abergavenny in the upper reaches of the river, which are apparently being satisfactorily dealt with by the local authorities, and coming to the tidal portions of the river, serious complaints were made of the Afon Llywd.

"No fish can live in the Afon Llywd; so much so that we have even had fish killed in the Usk where it joins the Afon Llywd . . . Only last year on one occasion we found a large number of what we call salmon pink dead near the mouth of the Afon Llywd, absolutely in the Usk for a distance of 300 yards." While in addition to the actual destruction of fish the witness was of the opinion that the polluting matters coming from this stream prevented salmon from ascending the Usk. "Young fish have been killed and big fish have been seen to turn back." *

No evidence was given regarding any deleterious effects produced by the sewage of Newport, but as already mentioned, the Ebbw river was stated to be in an even worse condition as regards pollution than the Afon Llywd.

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* Royal Commission Salmon Fisheries Report. Evidence of the Clerk to the Usk and Ebbw Fishery Board, pp. 133-143.

RIVER USK AND TRIBUTARIES.

No.	Where Sample was collected.	From Surface or Bottom.	Date.	Time.	State of Tide.	Temperature of Water °C.	C.C. per Litre at N.T.P. Dissolved Oxygen.	Parts per 1,000.	Parts per 100,000.		
								Chlorine.	*Nitrogen as :—		
									Free Ammonia.	Albd. Ammonia.	Nitrates.
1	Afon Llywd, near junction with Usk - -	S.	Aug. 9th, 1904	11 a.m.	Low Water	?	7·21	0·029	0·166	0·026	0·056
2	River Usk, above junction with Afon Llywd	S.	" " "	11.30 a.m.	Low Water	?	6·60	0·020	Trace	0·018	0·134
3	River Usk, Newport, near E. Usk Sewer -	S.	" " "	3.0 p.m.	About $\frac{1}{2}$-Flood	19·2° C.	4·41	8·32	0·080	0·028	—
4	River Usk, just below Caerleon Bridge -	B.	" " "	4.0 p.m.	About $\frac{3}{4}$-Flood	—	—	7·50	0·002	0·017	0·085
	" " " " " - -	S.	" " "	4.0 p.m.	About $\frac{3}{4}$-Flood	20·0	4·08	—	—	—	—
5	River Usk, about $\frac{1}{4}$ mile above Glen Usk	S.	" " "	5.30 p.m.	About High Water	19·8	3·78	1·72	0·025	0·026	0·094
6	At Mouth of Ebbw River - - - -	B. (5ft. from S.)	Aug. 10th, 1904	10.11 a.m.	More than $\frac{3}{4}$-Ebb	18·2	5·27	10·97	0·062	0·035	0·014
	" " " " - - - -	S.	" " "	10.11 a.m.	More than $\frac{3}{4}$-Ebb	18·2	4·92	10·69	—	—	—
7	About 1 Mile below Ebbw River - -	B.	" " "	11.25 a.m.	Nearly Low Water	18·6	4·36	7·10	0·012	0·015	—
	" " " " " - -	S.	" " "	11.25 a.m.	Nearly Low Water	18·6	4·59	—	—	—	—
8	Off St. Bride's in Bristol Channel - -	B. (25ft. from S.)	" " "	1.15 a.m.	Young Flood	19·2	4·83	13·00	—	—	—
	" " " " - - -	S.	" " "	1.15 a.m.	Young Flood	19·2	5·19	13·00	—	—	—
9	Just above Newport Bridge - - -	—	" " "	3.0 a.m.	$\frac{1}{2}$-Flood	—	—	3·82	0·062	0·056	—
10	At Mouth of Afon Llywd - - -	S.	" " "	5.10 a.m.	Nearly High Water	19·6	5.10	—	—	—	—

* Analyses by Dr. Howard Jones.

VISIT TO NEWPORT AND THE ESTUARY OF THE USK.

We visited this district on the 9th and 10th of August, 1904, and we desire to express our thanks to the Mayor of Newport, Councillor W. C. Phillips, Dr. Howard Jones, the Medical Officer of Health, Mr. R. H. Haynes, the Engineer, who received us with great kindness, gave us all the information in their power, provided us with a launch for inspecting and examining the river, and made every arrangement possible to enable us to spend our time to the best advantage. We are under special obligations to Dr. Jones, as he accompanied us on all our inspections and most kindly made several analyses of water samples for us in his laboratory.

Our first inspection was that of the Afon Llywd, and the Usk near the junction of the two streams.

For that purpose we drove to the bridge over the first of these two, a little above Caerleon, timing our visit so as to arrive about low water.

The Afon Llywd is here a small stream 7 to 8 yards wide. The water was very brown and turbid and the stones in it were covered with a brown deposit apparently of oxide of iron. Possibly this was derived from the "pickling" liquors of tinplate works, situated further up stream. On the whole the stream was sluggish, but there were occasional rapids. The bridge is situated practically at the tidal limit, but we were informed that spring tides run about 100 yards further up stream. The volume of non-tidal water descending the Afon Llywd is small compared with that of the Usk.

From the analysis which we give further on, this water, though saturated with oxygen on the day of our visit, was unmistakably polluted with sewage.

THE USK JUST ABOVE ITS JUNCTION WITH THE AFON LLYWD.

The banks of the Usk are generally extraordinarily muddy so that the collection of a sample of water at low tide is no easy task. This was specially the case near the Afon Llywd, and great difficulty was experienced in reaching the river. Finally a spot was found about one-third of a mile above the confluence of the two rivers where the bed of the stream was stony. But to reach it a steep mud bank had to be negotiated. This could only be done by wading up to the knees in mud down the bank, and care was necessary to avoid being completely bogged. This mud, though brown at the surface, was black about an inch below, but was not distinctly offensive. At the waterside the stones gave a good footing and a sample of the water was easily collected. The river was shallow here and fordable, but as before mentioned it was low tide at the time of our examination and only fresh water was descending. This, as its analysis shows, was rich in dissolved oxygen and practically free from sewage pollution.

It should be mentioned that plenty of *Enteromorpha* was growing on the stones in the river's bed, and the green vegetation which we noticed in fair quantity between Newport and Caerleon was probably the same *alga*.

THE USK FROM NEWPORT TO GLEN USK DURING THE FLOOD TIDE.

We examined this reach of the river from a launch when the tide had risen sufficiently, collecting samples of the water on the way.

Starting from the Pontoon Landing Stage the first sample was collected just above the two bridges which span the river at the town, and in the neighbourhood of one of the sewer outfalls. The next sample was collected immediately below Caerleon Bridge and the last immediately above Glen Usk.

The results of the dissolved oxygen determinations (made on the launch at the time of collection) are very different from those of the waters of the Afon Llywd and Usk earlier on the same day during the ebb tide when fresh water was alone present in their channels. These samples were practically fully aerated, whereas those collected on the flood tide only contained 80 to 70 per cent. of the dissolved oxygen corresponding with the air saturation value at the particular temperature, and these figures are considerably reduced if the salinity of the water is taken into consideration, probably to 74—60 per cent. It will be seen that the actual amount of dissolved oxygen gradually decreased as the river was ascended.

From the analyses of the water which Dr. Jones was so good as to perform for us, there are clear indications (as might, of course, be expected) of sewage pollution at Newport: at Caerleon scarcely any: while at Glen Usk pollution again appears to be present—possibly from some local cause.

We should mention that we made a second trip in the launch up the Usk as far as its junction with the Afon Llywd and found at that spot a much higher amount of dissolved oxygen than in any of the samples just referred to, while the chlorine was far lower, indicating no doubt a higher proportion of fresh water.

We have before alluded to the extraordinary amount of mud present both on the bed of the Usk in its tidal reach, and also in suspension in the water—which very possibly affects the dissolved oxygen (see pp. 383 and 131–134).

THE USK FROM NEWPORT TO THE SEA.

We examined this reach of the river from the launch, starting from Newport at half ebb.

Two samples of water were collected at the mouth of the Ebbw river—one from the surface and the other from the bottom. It will be seen from the table of analyses that sewage pollution was clearly indicated, and that both the chlorine and dissolved oxygen were distinctly higher in the bottom sample—indicating possibly a stream of sea water carried upwards on the flood tide and descending on the ebb, while the fresher and more polluted water remained on the surface.

The next samples were collected about a mile below the mouth of the Ebbw river and during the last hour of the ebb, and as in the previous case, both a surface and bottom sample were examined. The water here was remarkably turbid. The dissolved oxygen was found to be distinctly lower in both samples than in those collected previously at the mouth of the Ebbw river, but was slightly higher on the surface than in the bottom sample.

The launch was anchored at this spot for some time and determinations of chlorine were made at intervals on surface samples of the water. Variations in its amount occurred rapidly as the following figures show :—

Time.	Parts of Chlorine per 1,000 of the water.
11.40	8·28
12.0	7·41
12.25	6·51
12.35	6·57

The last sample was examined practically at low water, and the amount of chlorine found corresponds for all practical purposes with a mixture of one-third sea water and two-thirds fresh.

The next samples were collected outside the river and off St. Bride's, which is practically in the Bristol Channel. By this time the tide had turned, and the flood stream (estimated as being then five knots an hour) was setting towards the river's mouth. Two samples were collected as before—one from the surface water, which at the time was agitated by a fairly strong breeze and tidal jabble, and the other from near the bottom, which was about 25 feet deep. The chlorine content of both was the same, namely 13·0 parts per 1,000 of the water, but the dissolved oxygen was somewhat higher in the surface (5·19) than in the bottom sample (4·83)—a result which was only natural from the existing conditions.

The average chlorine content of sea water is probably rather over 19 parts per 1,000 and therefore the amount found outside the river corresponds with about two-thirds of such salinity.

For a temperature of 19°C. the amount of dissolved oxygen in fully aerated sea water is 5·41; and for distilled water 6·66 c.c. per litre at N.T.P.

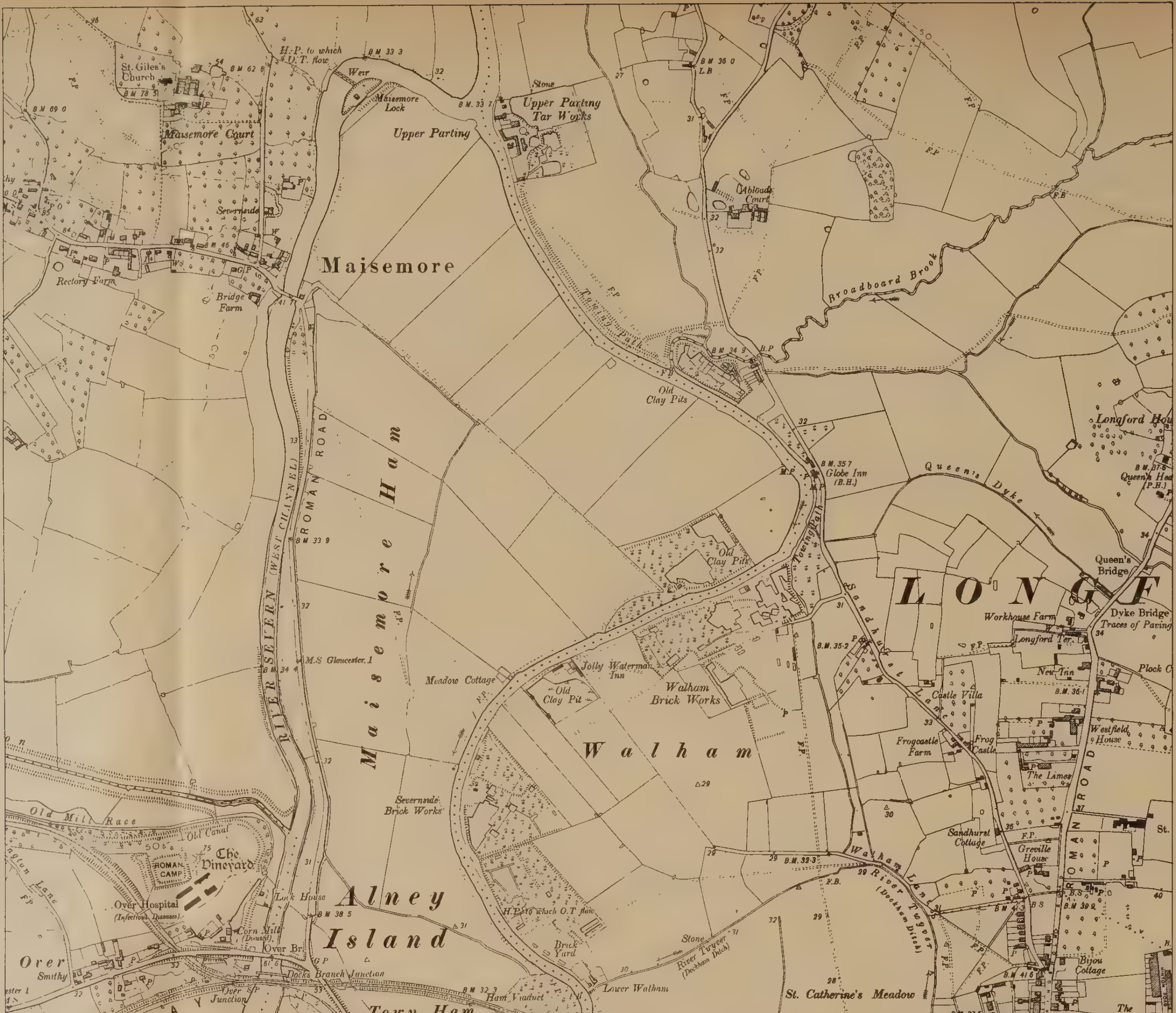
Supposing then that in a mixture of the two, each retains its own capacity as regard air saturation, two-thirds of sea water mixed with one-third of fresh water would, if fully aerated at 19°C., hold in solution $\frac{2\,(5{\cdot}41) + 6{\cdot}66}{3} = 5{\cdot}82$ c.c. per litre. The amount of dissolved oxygen actually found in the surface sample is only 89 per cent. of this, and in the bottom sample 83 per cent, from which it would appear that the water entering the Usk on the flood tide from the Bristol Channel is not fully saturated with oxygen, which we do not think surprising in view of the extensive area drained by the Severn estuary and the amount of silt the water contains.

E. A. L.

SECTION 7J.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

GLOUCESTER AND THE SEVERN.



GLOUCESTER AND SEVERN

SCALE OF MILES

0 ¼ ½ ¾ 1 Mile

Ordnance Survey Office, Southampton, 1907.

GLOUCESTER AND THE SEVERN.

We included this district among the localities we visited chiefly because of the evidence given before the Royal Commission on Salmon Fisheries to the effect that the sewage of the City of Gloucester, which is thrown into the Severn in an untreated condition, acts deleteriously on the fishing industry by hindering the passage of salmon.

The Severn Fishery District is a highly important one, the number of salmon taken in 1883 having been as high as 30,000, of a total weight of 389,760 lbs.—excluding the catches by rod and line. That, however, would appear from the statistics to have been a record year, before and after which the number of fish caught fluctuated very considerably; and in recent years the average take has been much less; the Chairman of the Fishery Board stating in his evidence before the Royal Commission on Salmon Fisheries in 1900, that since 1890 the drop had been continuous, and that "we cannot get now above 15,000 fish."

This diminution he attributed mainly to the removal of water by the Liverpool Water Works at Vrynwy, which in his opinion has not only spoilt the breeding grounds of the salmon in the upper reaches of the river, but had doubled the capturing power of the nets, etc., lower down, and in addition had further acted injuriously by reducing the amount of flood water, more especially in summer freshets, thus preventing the fish from ascending the river by the fish passes in the different weirs, and also doing away to some extent with the flushing of the river, which formerly cleared out accumulations of polluting matters, thus accentuating the question of pollution. Concerning this latter point the Chairman of the Fishery Board regarded the pollution of the Severn by the Gloucester sewage as of special importance, not by killing salmon, but by causing them to turn back in the tideway, and to be netted out or captured below Gloucester—so preventing a sufficient number of fish from ascending the river and spawning.

* * * * * * * * * *

Our visit to Gloucester was a very brief one, and we were only able to spend part of one day in examining the river (August 11th, 1904). Our thanks are due to the City Authorities and especially to Mr. E. S. Hartland, the Deputy Mayor, and Mr. Read, the City Surveyor, for their kindness in giving us all the information we required, and for making arrangements whereby we were enabled to make the best use possible of our time. A steamboat was placed at our disposal, which enabled us to inspect and examine the river, and Mr. Read, and Mr. Embrey, the City Analyst, kindly accompanied us on board.

Before describing the results of our observations we may give the following particulars. The Severn for some miles above Gloucester is a stream some 50 yards wide. About two miles as the crow flies above the city it divides at the "Upper Parting" into two divergent channels which are respectively called the "Eastern Channel" or "Gloucester River," and the "Western Channel" or "Maisemore River." The first of these is the narrower and more crooked, the second being broader and, relatively speaking, straight. The two branches again unite into a single stream at the "Lower Parting" which is situated about a mile from the city in a westerly direction. The land enclosed by the two branches is called "Alney Island."

Both the Eastern and Western Channels have a lock and weir. These latter, in the case of the Eastern Channel, are situated close to the city and about half a mile above the Lower Parting, while in the Western Channel they are placed less than a quarter of a mile below the Upper Parting.

These locks and weirs form the limit of tidal influence for ordinary tides, but during springs, the tidal current flows over both weirs and affects the height of the river as far up as Tewkesbury which is 16 miles above Gloucester.

The phenomenon of the "Bore" or tidal wave is well marked in the neighbourhood of Gloucester. This wave which at times reaches a height of 9 feet, and occurs regularly at spring tides, travels up the estuary and arriving at the Lower Parting passes chiefly up the Western Channel, and after shooting the weir there near the Upper Parting, is deflected backwards down the Eastern Channel, where it comes in contact with part of the wave which is ascending the same channel.

Gloucester is a port, connected with the sea by the Gloucester and Berkeley Ship Canal,16 miles in length, which opens into Severn Estuary at Sharpness, which is situated about 14 miles, as the crow flies, from Gloucester. There is no lock between the entrance lock at Gloucester and the tidal basin at Sharpness.

The rise and fall of the tide at Sharpness is at neaps 14 feet and at springs 30 feet.

Any tide rising above 24 feet at Sharpness shoots the weirs at Gloucester and affects the river higher up.

The population of Gloucester was in round numbers 48,000 at the last census. The water allowance per head is now about 20 gallons; thus giving about a million gallons as the daily dry weather sewage flow. This sewage we were informed is practically entirely of a domestic nature, and the city is virtually water closeted throughout. The sewage is discharged into the Severn (Eastern Channel) in an untreated condition, five-sixths of the total amount passing through a single outfall, which is situated about 340 yards above the canal lock and 900 yards above the Llanthony lock and weir in the Eastern Channel. Here, however, it is enormously diluted, the dry weather flow in this branch of the river, amounting, we were informed, to about 300 million gallons per twenty-four hours.

* * * * * * * * * *

As the day of our visit to Gloucester happened to be that on which it was new moon, the tides were high and affected the river above the city. The actual rise at Sharpness was 26 feet 9 inches, and the tide flowed over the weirs into the upper river for one and a quarter hours, occasioning a rise of 2 feet 9 inches at Gloucester. This had dropped to 2 feet 4 inches when we started from the quay two hours later in the steamboat which had been placed at our disposal by the City Authorities.

Proceeding up stream we noticed that the water was brown and very turbid for a mile or two above Gloucester. This we were told was caused by the tidal disturbance, the " bore " having passed up stream a few hours previously.*

Further up stream the turbidity rapidly decreased, and about 6 miles above Gloucester the water was quite clear, and is, we were informed, considered to be fit for drinking purposes by the boatmen.

During our trip on the steamboat the following determinations were made :—

1. About 500 yards above Upper Parting. Time 12.15 p.m. Temperature of the water 19·4°C.

   Surface Sample.—Dissolved oxygen 6·84 c.c. per litre at N.T.P. Chlorine 10·8 per 100,000.

   Bottom Sample (9 feet).—Dissolved oxygen 7·05 c.c. per litre at N.T.P. Chlorine 8·4 per 100,000,

2. About 6 miles above Gloucester. Time 12.45 p.m. Temperature of the water 19·4°C.

   Surface Sample.—Dissolved oxygen 6·97 c.c. per litre at N.T.P.

3. Abreast of Llanthony Lock, about 200 yards below main outfall. Time 2 p.m. Temperature of the water 19·2°C.

   Surface Sample.—Dissolved oxygen 4·89 c.c. per litre at N.T.P.

   Bottom Sample (3 feet).—Dissolved oxygen 4·74 c.c. per litre at N.T.P. Chlorine 8·0 per 100,000.

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* " Near Gloucester there is an island and the river divides itself into two branches. The Severn Commissioners have found that the Severn brings up a great deal of mud, and in consequence of these freshets being discontinued from the Vrynwy, they find the accumulation of mud there becoming so serious to the navigation that they have to employ a particular eroder as they call it to sweep away the mud after these neap tides. This mud being swept away meets the ascending fish and turns them back." Evidence of Mr. J. W. W. Bund, Royal Commission on Salmon Fisheries Report, Part II., Q. 4616.

General Conclusions.

While we were unable to make any exhaustive examination of the waters of the Severn in the neighbourhood of Gloucester, our observations on the amount of dissolved oxygen and of the general appearance of the river, such as they were, gave no indications that the discharge of the crude sewage from the city into the river is likely to act injuriously either hygienically or on the fishing industry. The flow of the river is so large in proportion to the pollution, that it seems improbable that a nuisance can arise at any time or that the dissolved oxygen can be so far reduced as to affect fish life.

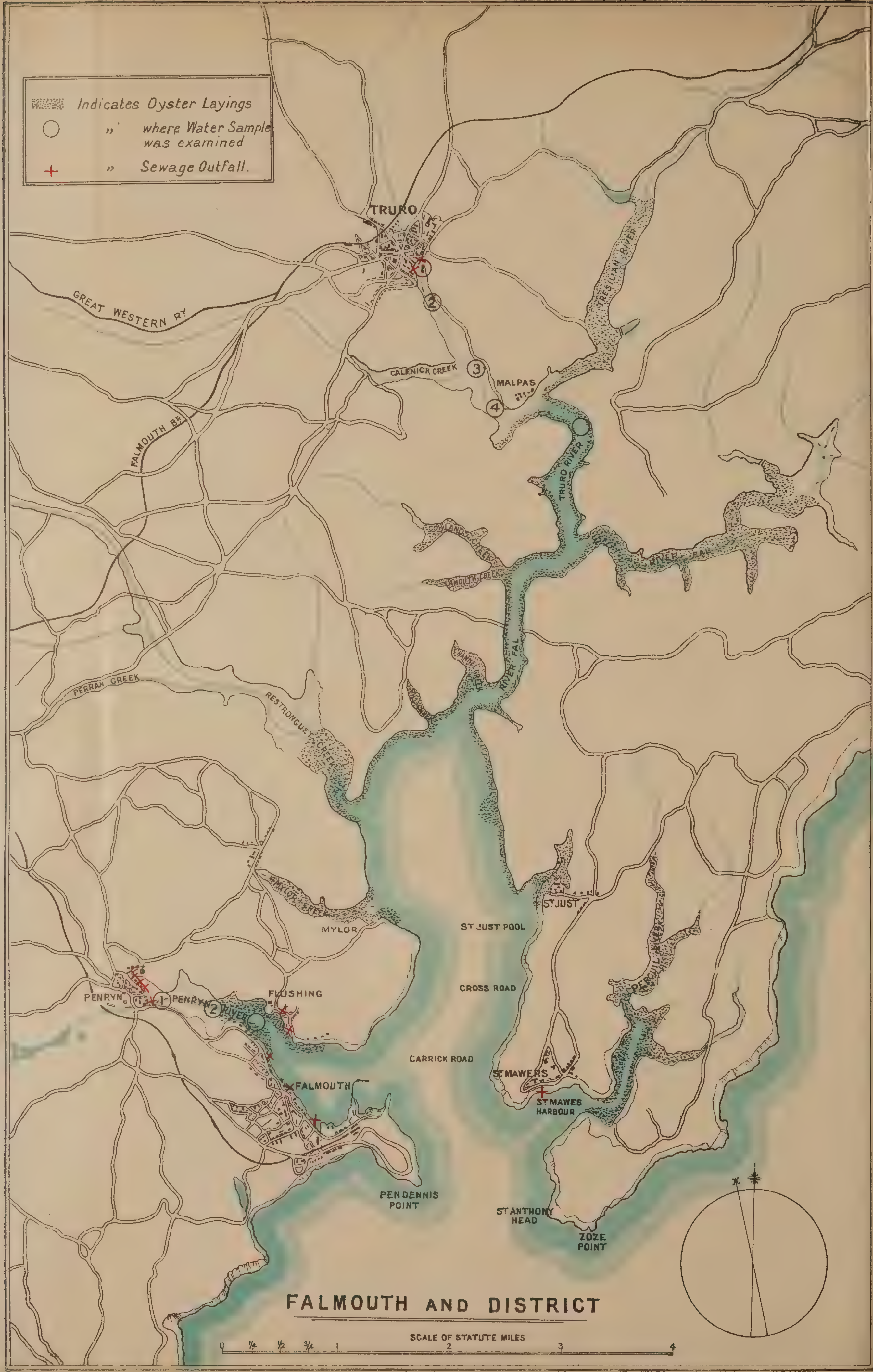
Regarding any possible effects of the Gloucester sewage on the passage of salmon; it should be remarked that the weirs in both the Eastern and Western Channels are provided with fish passes, so that a salmon either ascending or descending the river in the neighbourhood of Gloucester could avoid direct contact with the sewage by passing through the Western Channel. It would, it is true, have to pass through a zone polluted to some extent at or below the Lower Parting, but the dilution of the sewage in this zone is so great even in periods of drought, if our information is correct, as to render it improbable that the fish would be affected to any appreciable extent.

E. A. L.

SECTION 7K.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

FALMOUTH AND NEIGHBOURHOOD.



FALMOUTH AND DISTRICT

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FALMOUTH AND NEIGHBOURHOOD.

Falmouth is situated on an inlet of the English Channel, which in many respects resembles a Norwegian fiord or a Scotch firth.

The mouth of the inlet lies between Pendennis Point on the west and St. Anthony's Head on the east, and is rather more than a mile wide. A rocky obstruction called the Black Rock lies between these points, thus dividing the entrance into two channels, of which the eastern branch is both the broader and the deeper.

Inside the entrance, the waterway extends for about 4 miles in a northerly direction and of an average width of about 1 mile. Part of this sheet of water consists of a deep channel which at first extends somewhat to the north-west, forming Carrick Road, then to the north-east forming Cross Road and a little higher up St. Just's Pool, all of which furnish good anchorage for large ships.

Various creeks which are often called rivers branch off from the main waterway. One of these extends from near the main entrance for a little over two miles in a north-westerly direction, the town of Falmouth being situated on an indentation on the southern side of this, while the town of Penryn forms its upper extremity. The creek between the latter and Flushing (a village opposite the north-west end of Falmouth) is called the "Penryn River," but no fresh water to speak of descends it.

Another creek branches off on the eastern side of the main water way, the entrance of which forms St. Mawes Harbour, but above the town of St. Mawes it assumes a northerly direction as the Percuil River, with an easterly branch called Porth Creek, and terminates in Trethem Creek.

Above the Falmouth and St. Mawes inlets two other creeks open out, which are nearly opposite each other and are situated about two miles to the north of the mouth of the main inlet.

On the west is Mylor Creek which is about a mile in length, while on the east is St. Just's creek, which is much shorter. Some $\frac{3}{4}$ of a mile above Mylor, Restronguet Creek branches off on the west side and extends for about 4 miles in a north-westerly direction.

At the northern end of the main inlet the waterway contracts to a width of about $\frac{1}{4}$ of a mile, forming the entrance to the River Fal, close to which spot two other small creeks are found on the west side, namely, Pill Creek and Channel Creek.

The Fal extends for about a couple of miles in a northerly direction, but then divides into two branches, the main stream forming now the Truro River, while the Fal extends in an easterly or north-easterly direction to a series of creeks which form its origin. Its fresh water sources are mere streamlets running into the heads of these creeks, so that the Fal River is in reality a salt water stream. The Truro River a mile or so above its junction with the Fal also splits into two streams at the village of Malpas, the longer of which, called the Tresillian River, extends for about 3 miles in a north-easterly direction, while the shorter, called the Truro River, branches off to the north-west—the city of Truro being situated at the end of its tidal reach about $1\frac{1}{2}$ miles from Malpas. From the Truro River, about a mile below the city, the Calenick Creek extends in a westerly direction for some $\frac{3}{4}$ of a mile.

From this description it is apparent that the main sea inlet at Falmouth forms an inland tidal pond into which drain a number of creeks or so-called rivers, the upper parts of which are virtually muddy reaches at low water. No considerable body of fresh water descends any of these creeks or rivers, so that any scouring action in removing accumulations of foul matters must depend upon tidal effects. But as Truro and Penryn are situated at the heads of their respective rivers or creeks, these effects are necessarily but slight; while the town of Falmouth is in a bight where the water is shallow and the current tidal.

The hydrographic conditions of the locality are, therefore, of such a nature that the sewage from the three places just mentioned* (which are the most populous of the neighbourhood) is not thrown into a rapidly moving current, but tends to stagnate, and while nowhere causing—so far as we are aware—any direct nuisance, is calculated to produce indirect effects of the kind which we have described elsewhere in this report, such as the growth of green seaweeds.

Our visit to Falmouth and its neighbourhood occupied three days, namely, August 13th, 14th, and 15th, 1904, and here as at all the other places we visited the local authorities did their best to assist us in the purposes of our inquiry.

We are under special obligations in this respect to Mr. Tresidder, the Town Surveyor, who accompanied us on our tours of inspection to Truro and elsewhere, supplied us with the local information which we required, and devoted a large part of his time to us and the objects of our visit.

We devoted the first day to an examination of the River Fal and the Truro River, and for this purpose we hired a steam launch. Starting in this from Falmouth, we found however, that owing to the state of the tide we could get no further than Malpas where, as already stated, the Turo river diverges from the Tresillian River.

Leaving the boat at this place we drove to the city of Truro, and then walked back to Malpas, examining the stream on the way.

We arrived at Truro at low water. Here the creek or river is about 100 yards wide, but at low tide it is dry, with the exception of a fresh water stream (the Allen River) about 25 feet wide and 6 to 8 inches deep, which passes through Truro and receives, we were informed, all the sewage of the city. The mud banks at the side of this stream below the quay were brown on the surface but black and very foul below. Owing to excavating work which was being carried on above the quay the water of this stream was quite black, but higher up it was fairly clear. It should be mentioned that the current was sluggish, the rate of flow being, perhaps, about a mile per hour.

From Truro to Malpas the creek at low water consists of extensive mud flats through which the narrow fresh water stream flows in a zigzag direction. Calenick Creek forms a branch which extends for about a mile in a westerly direction and joins the main creek somewhat to the north of Malpas. The mud in these creeks is often 2 feet deep, and we had to engage a man to wade through it to collect samples of water for examination from the fresh water stream. For about a mile below Truro the mud is black and foul below the surface, but lower down it is clean, and the bed of the stream also clean and the water free from suspended matters.

Green vegetation is very abundant below Truro and thence to Malpas, *Ulva latissima* different varieties of *Enteromorpha,* and also *Zostera marina* being present in quantity.

Calenick Creek in especial seemed covered with green seaweeds, but as we could only examine it from a distance we are unable to say what species were present.

The following determinations of dissolved oxygen† in the water of the Truro Creek were made, but owing to the difficulty experienced in collecting the samples, and the adverse conditions under which the determinations were made, the latter are probably only approximately correct. They show at all events that there is evidence of sewage pollution for a considerable distance below Truro, which is also distinctly indicated both by the appearance of the mud and the growth of green seaweed in quantity.

1. About 300 yards below the quay at Truro. Water turbid with some black suspended matter. Time 1.15 p.m. Temperature 18·8° C.
   Dissolved oxygen 4·62 c.c. per litre at N.T.P.

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* The village or small town of Flushing, with two sewage outfalls on the shore, also contributes to the pollution.

† The localities from which the samples were collected are marked in the map by numbered circles.

2. About a mile below Truro. Stream about 40 feet wide and from 9 to 10 inches deep. Water turbid and similar to No. 1 in appearance. Mud still black beneath the surface. Time 1.30 p.m. Temperature 20·4° C.
Dissolved oxygen 3·75 c.c. per litre at N.T.P.

3. About 1½ miles below Truro. Mud not black beneath surface and bed of stream clean looking. Water now clear. Time 1.45 p.m. Temperature 20·6°C.
Dissolved oxygen 3·98 c.c. per litre at N.T.P.

4. Just above Malpas. Mud and water similar to 3. Time 2 p.m.
Dissolved oxygen 5·91 c.c. per litre at N.T.P.

Falmouth and the Penryn River.

The question of the disposal of the sewage at Falmouth, Penryn, and Flushing, and the other towns and villages situated in the inlet is an important one more especially from two points of view. In the first place the town of Falmouth has become an important health resort in the winter, while during the summer it is a favourite watering place. In the second place the locality is the seat of an extensive oyster fishery. We were told that the main dredging grounds are situated between St. Mawes Point and Malpas, a stretch of water along which no towns are situated and which is, therefore, not subjected to any extensive or immediate sewage pollution.

Sir Charles Petrie, however, in his evidence before this Commission* gives in the list of oyster "beds," "layings," and "ponds" in England and Wales the following as being situated at Falmouth:—

St. Mawes Creek (Percuil River).
St. Just Creek.
Penryn River.

While it is not within our province to discuss the question of shellfish in relation to sewage pollution, we may at least be permitted to remark that the conditions in the Penryn River† at all events are by no means ideal for the culture of oysters which shall be above suspicion of sewage contamination, and we may incidentally mention that a boatman whom we had occasion to employ not only showed us oysters which he had taken from a spot quite close to a sewage outfall, the shells of which were blackened, but ate them in our presence, expressing surprise at our disinclination to do so ourselves.

It seems difficult to persuade the humbler members of society who are engaged in collecting shellfish of the dangers of gathering the latter in obviously polluted localities, a fact which we have repeatedly noticed elsewhere.

Regarding the disposal of the Falmouth sewage, we were officially informed that it is submitted to a process of chemical precipitation (lime and sulphate of alumina)‡ before discharge through the outfalls, of which there are two, one situated to the east of the town and close to the railway station and harbour (Arwenack outfall) discharging about one-third of the total effluent, the other at Market Strand, discharging the remainder (Market Strand outfall). The necessary precipitation tanks are situated at both outfalls and the solids are taken out to sea in barges.

There is also a small outfall to the west of the town at Greenbank Quay from which crude sewage is discharged. It should be mentioned that the water is shallow in the neighbourhood of all the outfalls and that the tidal current is not a strong one.

Green seaweeds are plentiful about Falmouth, abundance of *Ulva latissima* and different species of *Enteromorpha* occurring all the way from Greenbank to the Market Strand outfall, and at the time of our visit the shore was covered with them from low water mark to about half tide level. *Ulva latissima* was specially abundant at the Market Strand outfall, and Mr. Tresidder informed us that this seaweed often accumulates along the foreshore and at times gives rise to a nuisance.

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* Third Report, p. 274.

† See also Dr. Houston's report on this river in Vol. II., the Supplement to the Fourth Report of this Commission, Vol. III., p. 132.

‡ Mr. Tresidder has written to us as follows:—"The use of sulphate of alumina for treating the Falmouth has been stopped for some time, and at the date of your visit the use of these chemicals had been considerably reduced."

PENRYN AND THE PENRYN RIVER.

The town of Penryn lies at the head of the Penryn River which, as already stated, is merely a salt water creek, but two fresh water streamlets flow in at the town itself. The creek is muddy during low tide at, and for some half mile below, the town.

Penryn has a population of about 4,000 and the sewage is discharged into the creek in an untreated condition.

We rowed from Falmouth to Penryn in a small boat, and, after landing, made the two following examinations of the water on our way back.

1. *Head of Penryn River.*

The water was discoloured and contained finely divided suspended matter. The surface was greasy, possibly from discharges from either the gas works or chemical factory which were close by.

Time 12.25 p.m. Temperature 16·4° C.

Chlorine - - - - - - 18·4 per 1,000.
Dissolved oxygen - - - - - 6·53 c.c. per litre at N.T.P.

2. *Midway between Penryn and Falmouth.*

The water still contained some suspended matter, but perhaps less than the first sample. Surface looked clean.

Time 12.40 p.m. Temperature 16·4° C.

Chlorine - - - - - - 19·46 per 1,000.
Dissolved oxygen - - - - - 6·19 c.c. per litre at N.T.P.

It should be mentioned that a gale had been blowing from a north-westerly direction during the previous night with much rain, and there was a strong wind all the time we were in the boat.

As we wished to examine the water and could only do so when the tide was in, we had no opportunity of examining the condition of the banks when exposed at low water.

HELFORD RIVER.

This is really a sea inlet like Falmouth Harbour, though much smaller.

It extends inland for 5 or 6 miles in a westerly direction and branches off into several smaller creeks on both sides. Its mouth lies between 3 and 4 miles to the south (and a little to the west) of Falmouth.

It is a seat of the oyster industry, and as no towns are situated on its banks there is no possibility of any extensive sewage pollution of its waters.

Owing to the limited time at our disposal we were only able to inspect the Helford River at Gweek, a village having a population of about 150 and situated near its upper extremity.

We reached this place by driving from Falmouth and arrived at low water. The creek here is about a quarter of a mile wide and consists of a mud flat. Green seaweeds were fairly abundant—*Ulva latissima* in isolated patches, but *Enteromorpha* was plentiful.

A sample of the water collected here contained 6·69 c.c. of dissolved oxygen at N.T.P.

E. A. L.

SECTION 7L.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

SOUTHAMPTON.

ORDNANCE SURVEY OF ENGLAND (*Third Edition*)

SOUTHAMPTON

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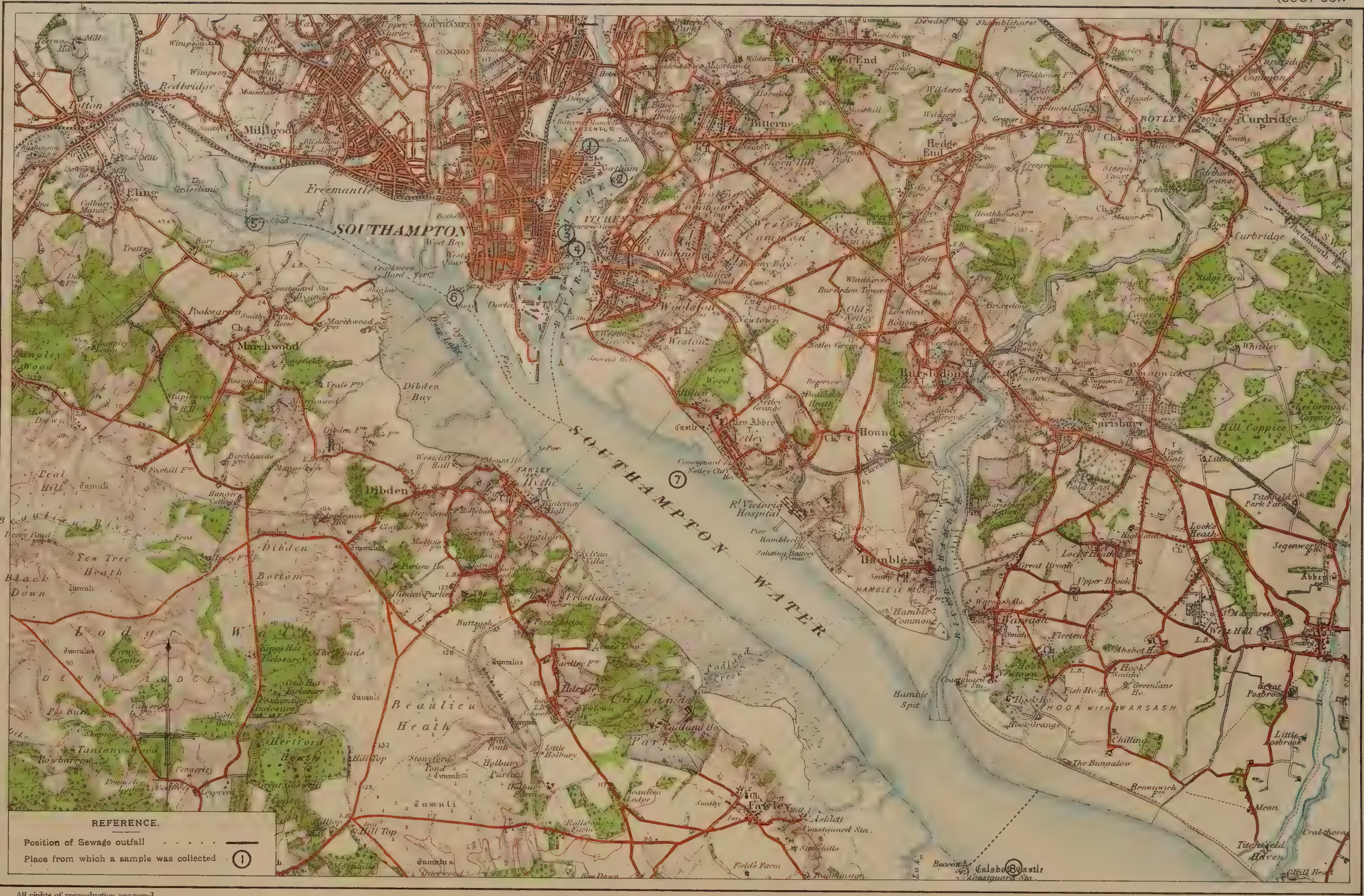

REFERENCE.

Position of Sewage outfall . . . . .

Place from which a sample was collected ①

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Scale of One Inch to One Statute Mile — $\frac{1}{63360}$

0 1 2 3 4 Miles

Printed at the Ordnance Survey Office, Southampton in 1906.

SOUTHAMPTON.

Estuaries of the Rivers Test and Itchen, also Southampton Water.

Southampton is situated between the rivers Test and Itchen and just at their junction. Both of these streams rise in Hampshire and have in each case a total length of between 20 and 30 miles, but the Test is the longer of the two. Southampton Water, one of the finest harbours in the kingdom, forms the lower extremity of the joint estuary of the two rivers. It is a sheet of water which extends for about 6 miles in a south-easterly direction from Southampton to the Solent and has an average width of about ¾ of a mile At low water extensive mud banks are exposed more especially on the southern or western-side. The tides are somewhat peculiar in Southampton Water as there are two consecutive high tides, the second of which occurs two and a half hours after the first, but there is only one corresponding low tide. The rise and fall amounts to 13 feet during spring tides and to 9½ feet during neaps.

The population of (the drainage area of) the town of Southampton is 112,000. The main bulk of the sewage (approximately 3,000,000 gallons per twenty-four hours dry weather flow) is discharged from one outfall into the river Itchen (after partial subsidence in tanks), while other though smaller outfalls are situated higher up the same river and one lower down. Virtually, therefore, all the sewage of the district is thrown into this river, the greater part being discharged during the ebb tide. The sewage is chiefly of a domestic nature, but several breweries and one or two small dye works discharge their trade effluents, into the sewers.

Visit to Southampton and District.

We visited this locality in August, 1904, and we desire to express our thanks to the Town Clerk and to Mr. Crowther, Engineer to the Corporation of Southampton, for their kind assistance, and to the Port Sanitary Authorities who were so good as to lend their steam launch for the purposes of our inspection and examination of the waters of the district. Starting in this launch with Mr. Crowther, who very kindly accompanied us and gave us the local information we required, we steamed up the river Itchen for about 2½ miles to Northam Bridge, which was as high as the boat could go at low water. This stretch of the river varies in width, at low water from about ¼ of a mile near its mouth to some 200 yards at the place where we stopped. At Northam Bridge we collected and examined a sample of the water with the following results :—

(1) *River Itchen near Northam Bridge.*

August 20th, 1904. Time 11.10 a.m. (practically low tide). Temperature of the water 16·2° C.

Chlorine - - - - - -	9·1 per 1,000.
Dissolved oxygen - - - - -	4·74 c.c. per litre at N.T.P.

The water was somewhat turbid, with patches of grease and floating matters on the surface ; otherwise clean looking. The launch was now turned and we proceeded down stream for a short distance when a second sample was collected and examined.

(2) *River Itchen ¾ mile below Northam Bridge.*

Time 11.20. Temperature of the water 16·8° C.

Chlorine - - - - - -	10·4 per 1,000.
Dissolved oxygen - - - - -	4·68 c.c. per litre at N.T.P.

Condition of the water much as before. Still proceeding down stream, the next sample were collected near the main sewage outfall.

(3) *River Itchen about* 1½ *miles below Northam Bridge and about* 100 *yards above the main sewage outfall.*

Time 11.35 a.m. Temperature of the water 18·2° C.

Chlorine - - - - - - 10·0 per 1,000.
Dissolved oxygen - - - - - 4·33 c.c. per litre at N.T.P.

(4) *River Itchen about* 100 *yards below the main sewage outfall.*

Time 11.45 a.m. Temperature of the water 17·8° C.

Chlorine - - - - - - 11·0 per 1,000.
Dissolved oxygen - - - - - 4·67 c.c. per litre at N.T.P.

The water was discoloured but not exactly dirty. The bed of the river inshore was evidently foul, and the launch's propeller stirred up a good deal of black mud.

After making the above examinations of the water of the Itchen and noting, as far as possible, the condition of its shores, the nature and extent of the aquatic vegetation on the latter, etc., we steamed out of the Itchen and up the Test as far as the depth of the water would permit, which was about 3 miles above Southampton. Here a sample of the water was collected and examined.

(5) *River Test about* 1 *mile below the Village of Eling.*

Time 12.45 p.m. (commencement of flood). Temperature of the water 18·2° C.

Chlorine - - - - - - 8·48 per 1,000.
Dissolved oxygen - - - - - 6·45 c.c. per litre at N.T.P.

The water was turbid but not dirty and there was some scum on the surface. At this place we took the small boat and rowed as far as we could towards the shore on the southern side. We found it muddy and black below the surface. The mud was too deep to permit our landing. There was an abundance of green seaweeds, among which we identified *Zostera marina*, *Enteromorpha intestinalis*, and *Ulva latissima*, but chiefly the latter, which occurred both rooted and in the detached condition, and the fronds were often large.

The boat was now turned and we proceeded down the Southampton Water, stopping from time to time to collect and examine samples of the water.

(6) *River Test. Off the Royal Pier, Southampton.*

Time 1.25 p.m. Temperature of the water 19·2° C.

Chlorine - - - - - - 16·0 per 1,000.
Dissolved oxygen - - - - - 5·67 c.c. per litre at N.T.P.

The water here was clean and clear. Near the pier green seaweeds were fairly abundant, but *Zostera marina* seemed more prevalent than the other varieties.

(7) *Southampton Water. Abreast of Netley about* 2 *miles below Southampton.*

Time 5.30 p.m. (nearly high water). Temperature of the water 18·4° C.

Chlorine - - - - - - 19·6 per 1,000.
Dissolved oxygen - - - - - 5·64 c.c. per litre at N.T.P.

(8) *Southampton Water at its junction with the Solent near Calshot Castle.*

Time 6.15 p.m. Temperature of the water 18·4° C.

Chlorine - - - - - - 19·61 per 1,000.
Dissolved oxygen - - - - - 5·64 c.c. per litre at N.T.P.

The following is a summary of the examinations made of the waters of the Itchen, Test, and Southampton Water:—

Where Sample was Collected.	Temperature of Water.	Chlorine per 1,000.	Dissolved Oxygen (c.c. per litre at N.T.P.).
RIVER ITCHEN.			
1. Just below Northam Bridge - - - -	16·2	9·10	4·74
2. Three quarters of a mile below Northam Bridge	16·8	10·40	4·68
3. 100 Yards above Main Sewage Outfall - -	18·2	10·0	4·33
4. 100 Yards below Main Sewage Outfall - -	17·8	11·0	4·67
RIVER TEST AND SOUTHAMPTON WATER.			
5. About 2 miles above Southampton - - -	18·2	8·48	6·45
6. Off Royal Pier at Southampton - - -	19·2	16·0	5·67
7. Off Netley (about 2 miles below Southampton)	18·8	18·56	5·31
8. Off Calshot (about 7 miles below Southampton)	18·64	19·61	5·64

Regarding the above figures: in the Itchen, broadly speaking, all the samples were collected at low water, and at Northam Bridge the salinity for all practical purposes corresponded with a mixture of equal parts of fresh and sea water.

At 16° C., one litre of fresh water saturated with air contains 7·06 c.c. of dissolved oxygen, and one litre of sea water, similarly saturated, contains 5·72 c.c. The mean of these figures is 6·39, whereas the amount of dissolved oxygen actually found was only 4·74 c.c. which corresponds with 74 per cent. of the air saturation value.

The other figures found for the dissolved oxygen in this river do not differ very considerably from this, but the slight decease in salinity coupled with the slight decrease in dissolved oxygen found in the third sample was in all probability caused by the sewage escaping from the main outfall.

On the whole the results obtained indicate considerable pollution of the waters of this river.

The figures obtained with the samples taken from the Test and Southampton Water are very different. In the first of these which was collected in the Test about 2 miles above Southampton the salinity was much the same as, but a trifle below that of, the first sample examined in the Itchen. Broadly speaking, therefore, the water may be considered as having been, like the latter, a mixture of equal volumes of sea and fresh water. But the dissolved oxygen which it contained was very different from that of the Itchen sample and corresponded with complete air saturation.

The salinity of the next sample examined was quite different; as might have been expected both on account of the incoming tide which had been flowing for about two hours, and also from the fact that the sample was collected some 2 miles nearer the sea than the preceding one. This salinity approaches that of sea water itself, and at the temperature found (19° C.) the air saturation value for the dissolved oxygen in sea water is 5·41 c.c. per litre, while the amount of dissolved oxygen found in the sample was 5·67. So that although there was a sudden drop in the dissolved oxygen of this sample contrasted with that of the preceding one, it is accounted for by the increase in salinity, and in both cases the water was fully saturated with the gas.

The results obtained with the remaining sample examined call for no special comment as the fluctuations in the dissolved oxygen are inconsiderable and in both cases indicate full air saturation.

General Impression of the Locality.

In addition to examining the waters as described above, we devoted the greater part of another day to an inspection of the foreshores—more especially those of the Test which we examined when the tide was low.

The shores of the Itchen are very muddy, and as far as could be judged more or less foul.*

A fair amount of green seaweeds was seen, but not so much as in the Test. The Itchen has all the characteristics of a polluted stream.

Regarding the Test, both shores of the estuary both in the immediate neighbourhood of Southampton and for some miles higher up appeared very green, and this was specially noticeable on the western or southern side. But the foreshore on the Southampton side had very considerable deposits of both *Ulva* and *Zostera* at the time of our visit, not only quite close to the town, but also for some miles higher up. In fact an *Ulva* nuisance of some magnitude existed there, and we were informed that serious trouble had been caused by the seaweed from time to time, and that it had to be collected and carried by barges out to sea.

We were further informed that another nuisance occurs annually of a rather singular nature, about the month of July, the water turning red and acquiring a peculiar odour. We had no means of ascertaining the cause of this.

E. A. L.

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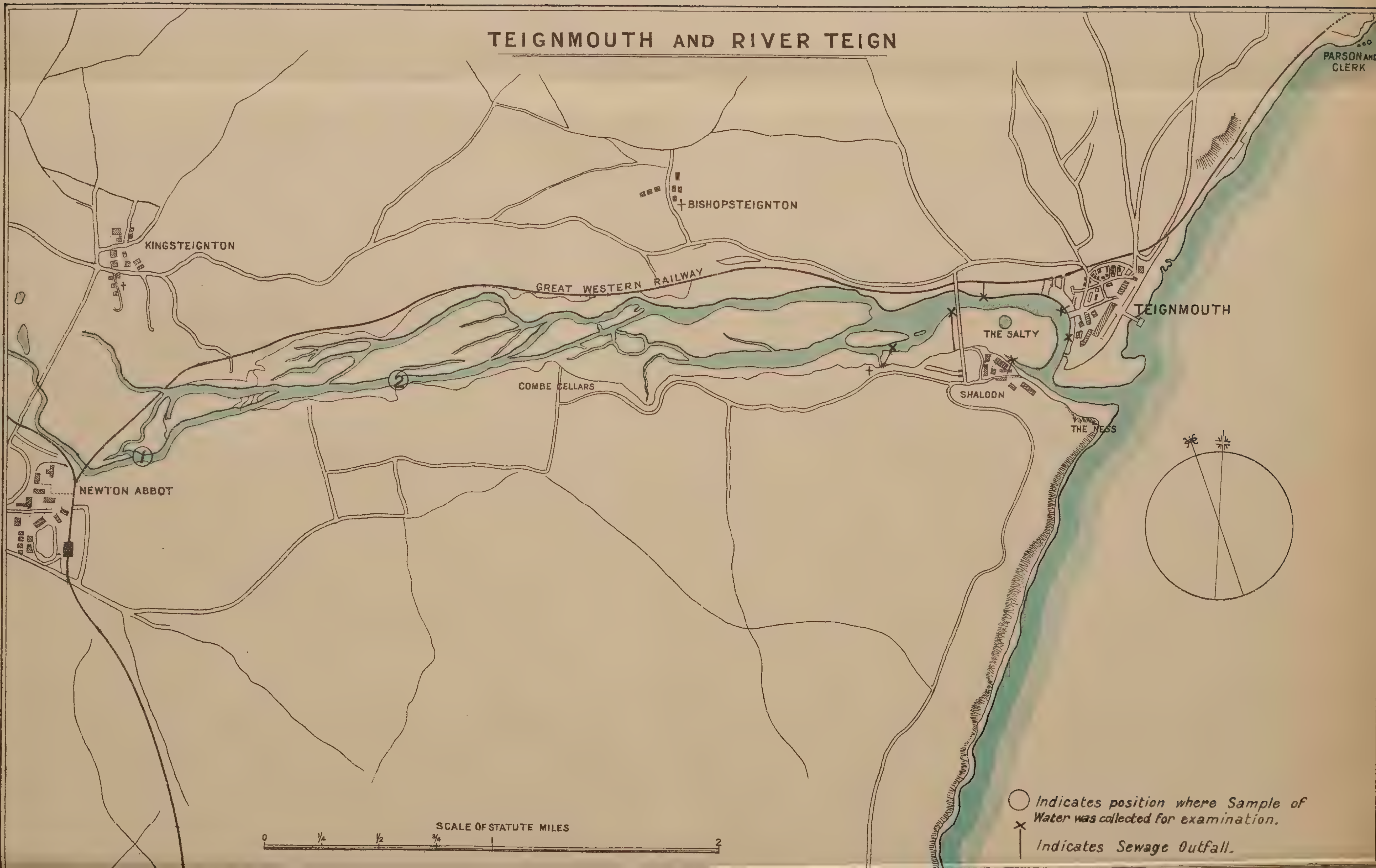
* "A considerable amount of mud-land surrounds the town, and in warm weather many persons object to the smell" (extract from answer to circular letter sent to Medical Officer of Health for Southampton).

SECTION 7M.

EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

TEIGNMOUTH.

TEIGNMOUTH AND RIVER TEIGN



TEIGNMOUTH.

Teignmouth, as its name implies, is situated at the mouth of the river Teign, a stream which has its sources on Dartmoor and has a total length of some 30 miles. A few miles above Newton Abbot the Teign is joined by the Bovey which also rises on Dartmoor. The estuary of the Teign extends from Teignmouth to a little above Newton Abbot—a distance of about 6 miles. It varies in width from about one half to one quarter of a mile, and at low water consists of extensive sand and mud banks which are then uncovered, through which the river flows in a number of tortuous channels and pools, but in the upper part of the estuary is controlled to some extent by training walls.

The actual mouth of the Teign is narrow, being only about 100 yards wide at low water. The tidal range during springs is about 13 feet, thus causing a rapid current at the mouth of the river.

The town of Newton Abbot has a population of 16,951, and its sewage is discharged in an untreated condition into the upper end of the estuary where the waterway is narrow.

The town of Teignmouth has a population about half as large (census 1901, 8,502; estimate for 1903, 8,540)—to which we were informed some 3,000 should be added for summer visitors—as the town is then a favourite watering place.

The sewage of Teignmouth and Shaldon (which faces it) on the southern side of the estuary, is discharged in the crude state from six outfalls, three of which are situated on the Teignmouth and three on the Shaldon side of the estuary, and at all states of the tide, with the exception of the (30 inch) main Teignmouth outfall which is the largest and most important. It discharges only on the ebb (beginning one hour after high water and ceasing one and a half hours before low water). All the sewage is discharged within the estuary, and none into the actual sea.

It is stated by the Medical Officer of Health that complaints have been common in summer as to floating solids from these outfalls being deposited on the foreshore, and that further complaints have been made regarding bad smells proceeding from the outfalls.

The Teign is a good fishing river and is under the control of the Teign Fishery Board. The net fishing is confined to the six miles or so of estuary, and in 1895 yielded 2,547 salmon and 1,130 sea trout of a total weight of 27,540 lbs. That, however, appears to have been an exceptional year, and probably the fishery was temporarily damaged then by over-netting, as the number of fish caught decreased considerably during the next three years. In the upper reaches of the river some seventy rod licenses are issued yearly. These upper reaches are subject to pollution from mines, and it is stated that the spawning grounds of the salmon are damaged by deposits from the china clay mines.

The sewage pollution of the estuary by the towns of Newton Abbot and Teignmouth (but more particularly by the former where the estuary is narrow) has been stated to prevent the fish from ascending the river,* but so far as we can ascertain it has not been found to exercise any more deleterious action.

We understand that Teignmouth is a centre of some importance for both cockles and mussels, and were informed that £1,200 per annum is paid in wages to the gatherers of these shell fish.

The Medical Officer of Health reported in 1904 that "all the local sewage outfalls are well on the seaward side of the shell fish beds, over which, however, the untreated sewage from the town of Newton Abbot and from a number of riparian villages flows in its passage towards the sea. There are important mussel beds in the river above Teignmouth, the molluscs being laid there to fatten and ultimately finding their way into the London and Midland markets. I have seen these prior to removal by train lying in bags in the river close to the main sewer outfall. Locally there is no undue prevalence of enteric fever, but scattered cases have been from time to time undoubtedly caused by mussels and cockles from the Teign as reported by me so long ago as 1893."

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* Evidence of the Clerk to the Teign Fishery Board—Roy. Com. on Salmon Fisheries Rep. Part II pp. 107 and 109.

Green Seaweeds.—The same gentleman reported that *Ulva latissima* is plentiful, floats to and fro with the tide, and is often deposited in decomposing state upon the large sand bank in the centre of the harbour, known as the "Salty." In late summer in 1895 an enormous quantity (250–300 tons) was washed into a hollow in the bar at the mouth of the river, and there lay decomposing for weeks. It caused great nuisance until buried *in situ* by the local authority.*

We visited Teignmouth in August, 1904, and we are under obligations to both the Town Clerk and to Dr. Piggott, the Medical Officer of Health for the district, who very kindly gave us all the information and assistance we required in the objects of our inquiry. For the purpose of examining the estuary we hired a launch at Teignmouth, and as the estuary is shallow at low water and it was our object to examine it up to Newton Abbot, and as far as possible when the banks were uncovered, we started from Teignmouth at about half ebb, and after a quick run arrived in a narrow part of the channel about a quarter of a mile below Newton Abbot Bridge.

Here a sample of the water was collected and examined with the following results:—

2.40 p.m. Temperature of the water 16·2° C.
Chlorine - - - - - - 0·046 per 1,000.
Dissolved oxygen - - - - 6·63 c.c. at N.T.P. per litre.

The water contained finely divided solids in suspension.

The launch was now turned and we proceeded down stream. A second sample of the water was collected $1\frac{1}{4}$ miles below Newton Abbot Bridge and examined with the following results:—

2.50 p.m. Temperature of the water 16·2° C.
Chlorine - - - - - - 1·52 per 1,000.
Dissolved oxygen - - - - 6·48 c.c. per litre at N.T.P.

As before the water contained finely divided solids in suspension.

We next proceeded to Combe Cellars and much green seaweed was noticed on the way down on both banks of the channel. A landing was made at this place in order to more closely examine the green vegetation on the banks which here was present in quantity.

It was found to consist of both *Ulva latissima* and *Enteromorpha intestinalis*, both rooted and cast ashore.

In places, and especially at the mouth of the small creek here, the shore was very muddy and the mud was black and foul beneath the surface.

Again joining the launch, it was now necessary owing to the shallowness of the water and the rapidly falling tide to proced down stream quickly; hence it was only possible to note the general condition of the mud and sand banks now exposed on both sides of the channel. Generally speaking these were green either from the presence on them of *ulva* or *enteromorpha*, and probably of both, but it was not possible to examine them closely.

Arriving at Teignmouth practically at low water, Dr. Piggott and the Town Clerk joined us and we examined the "Salty," which, as before stated, is an extensive sandbank in the estuary opposite Teignmouth, on which there is a circular depression or lagoon from which a spring of fresh water rises.

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* See Appendix, p. 547.

Our attention was directed by Dr. Piggott to the fact that this water though pure at its source became rather strongly charged with sulphuretted hydrogen as it made its way through the sand. As a considerable quantity of *ulva latissima* was present on the sandbank, we suspected that the fouling of the water was caused by its decomposition, and on digging into the sand found our surmise to be correct, abundance of the seaweed being discovered in a putrid condition some distance beneath its surface.

General Impression of the Teign Estuary.

The waters of the estuary in and about the harbour are particularly clear and clean looking and maintain that character to within a short distance of Newton Abbot, when the estuary contracts to a stream some 40 to 50 yards wide, which we found at half ebb to consist of rather turbid fresh water containing about 94 per cent. of the dissolved oxygen corresponding with the air saturation value.

There is thus abundance of dissolved oxygen for fish life even near the (presumably) most polluted reach of the river, nor did we see any indications that the sewage discharged into the estuary would be likely to affect the passage of *salmonidæ.*

The estuary is remarkable for the extensive banks exposed at low tide—partly sand and partly mud—and on these banks very extensive growths and deposits of green seaweeds occur. This is not surprising in view of the narrowness of the mouth of estuary and the considerable volume of sewage discharged into the estuary.

E. A. L.

SECTION 7N.

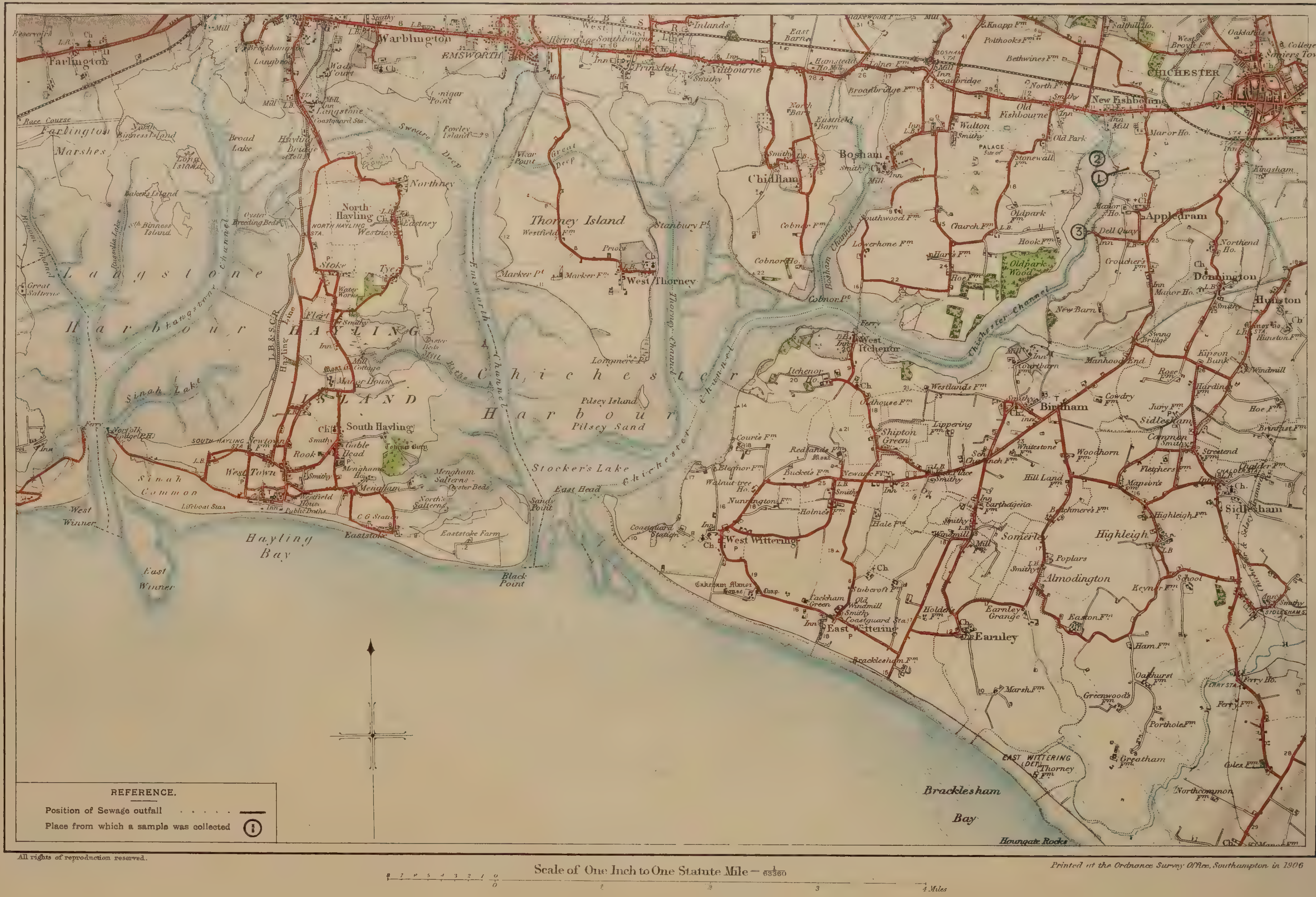
EXAMINATION OF SELECTED LOCALITIES WHERE THE TIDAL WATERS ARE POLLUTED.

CHICHESTER AND HARBOUR.

ORDNANCE SURVEY OF ENGLAND *(Third Edition.)*

CHICHESTER HARBOUR

PARTS OF SHEETS {316. 317. / 331. 332.



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Scale of One Inch to One Statute Mile — $\frac{1}{63360}$

Printed at the Ordnance Survey Office, Southampton in 1906

CHICHESTER AND HARBOUR.

We included this locality in our tour of inspection, as our attention had been drawn to it by a Report issued by the Medical Officer of Health for the East Sussex County Council to the local Fisheries Committee with regard to the pollution of Tidal Fishing Waters by Sewage, the Report dealing with the condition of New Shoreham Harbour, the tidal Adur, and Chichester Harbour.* We shall take the liberty of quoting somewhat fully from this Report before describing our own observations on the locality.

Foulerton's instructions were:—

> "To inspect, inquire, and report on the question whether the discharge of sewage into New Shoreham and Chichester Harbours respectively is, by the reason of the sewage or chemicals or otherwise, detrimental to sea fish or to sea fishing."

And he remarks that this was the first occasion on which a local Fisheries Committee had caused a thorough sanitary survey to be made of waters under their jurisdiction.

"Chichester Harbour is situated partly in Sussex and partly in Hampshire, at the extreme west of the area which comes under the jurisdiction of the local Fisheries Committee. . . .

The Harbour includes the main Chichester Channel, which runs generally in a north-easterly direction from the mouth of the Harbour, and three other channels, which run generally in a northerly direction from the main channel, *viz.*, Emsworth, Thorney, and Bosham Channels. . . . The head of Chichester Channel is situated to the west of the city of Chichester and close to the main road from Chichester to Havant. Here the Harbour comes into relation with the hamlet of Old Fishbourne in the rural district of Westbourne, and the village of New Fishbourne in the rural district of Westhampnett. It is believed that a certain amount of contamination of the Harbour water is caused by Old and New Fishbourne; but in any case the pollution is not of such extent as to require special consideration in this Report, and it is understood that a sewering scheme for the two places is under consideration. The whole of the southernmost bank of the Harbour is in the rural district of Westhampnett, and the following are the chief features of this bank which have to be mentioned in connection with this Report.

Close to the head of the Harbour at Appledram are situated the sewage outfall works of the city of Chichester. A few yards below the outfall is the mouth of the Lavant Course, a stream which rises in the neighbourhood of West Dean and passes through the Lavant district and the city of Chichester in its course to the Harbour. Below Appledram is situated Dell Quay: here there are several drains opening on the foreshore, the mud of which is particularly foul. Lower down again a short distance below Copper Point are Birdham Creek and Birdham Mill, and the Harbour is here joined by the Chichester and Arundel Canal.

Below Birdham Creek is West Itchenor, situated a little above the point at which Bosham Channel opens on the opposite bank. There does not appear to be any source of pollution here. From West Itchenor down to the mouth of the Harbour there are but a few isolated dwelling houses within a near distance of the water, and it is believed that there is no source of serious pollution in the neighbourhood.

The western bank of the Harbour, including the whole length of Emsworth Channel, is formed by the east shore of Hayling Island, a portion of the rural district of Havant. To the west of the mouth of the Harbour is situated the village of South Hayling, in the neighbourhood of which are the layings and storage ponds of the Ham and Sea Salter Oyster Company. A careful inspection of the locality failed to show the presence of any possible source of pollution here.

In Gutner Creek, situated some little distance up the east shore of the island, are some small private oyster layings: I have not inspected these, but I understand that there are no sources of pollution in their immediate neighbourhood.

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* Report by Alexander G. R. Foulerton, F.R.C.S., &c., issued October, 1903.

Towards the north Emsworth Channel reaches the town of Emsworth, from which place, together with an adjoining part of the rural district of Westbourne, gross pollution of the Harbour water arises. It is probable that but little contamination arises from either Thorney Island between Emsworth and Thorney Channel, or from the parish of Chidham, between Thorney and Bosham Channels.

Bosham village is situated on the east bank of Bosham Channel, about 1⅜ miles above the point where it joins the main channel. Bosham is a source of pollution of the water, but to an insignificant extent as compared with the town of Emsworth. On the east bank of the channel below Bosham there are a few farm buildings which possibly send a small amount of dirty water into the harbour; and on the west bank close to the mouth of the channel and to the Bosham Deep oyster layings there is Cobnor House, which, however, does not appear to discharge anything directly into the water.

The northernmost bank of the Harbour beyond Bosham Channel lies in the rural district of Westbourne, and does not present any outfalls of consequence.

From what has preceded it will have been seen that the three chief causes of pollution of the Harbour are:—

(1) The outfall works of the City of Chichester at Appledram.

(2) The crude sewage discharged from Emsworth and the adjoining part of the Wesbourne rural district.

(3) Sewage discharged into the harbour from Bosham."

Foulerton next goes on to speak of the disposal of the sewage from Chichester City, some of which before 1895 was discharged into the Harbour in an untreated condition by way of the Lavant Course. From that date till 1901 the sewage was treated by chemical precipitation and land irrigation.

But in 1901 Lord Giffard took action to obtain an injunction against the Corporation of Chichester to prevent the continuance of a nuisance alleged to be caused by the discharge of an imperfectly purified effluent into the Harbour, and also to recover damages. After a hearing of considerable length in the King's Bench Division, the injunction was granted and the plaintiff awarded nominal damages.

After some delay the improvement of the outfall works was taken in hand and at the time of our visit (August, 1904) the purification plant was in full operation. We shall describe it presently.

Regarding the sewage of Bosham, Foulerton gives the following particulars:— Population in 1901, 1,149; inhabited houses, 273; the sewage from most of which is disposed of in cess pits. A few of the houses, however, discharge their privies on to the foreshore and a number of pipe drains discharge slop water in the same way. He also gives the following particulars regarding Emsworth, situated in the urban district of Warblington. This district at the census of 1901 had a population of 3,639 and of these about 1,600 resided at Emsworth. Regarding this place he says:—

"Emsworth is provided with two main sewers, which discharge at points to the east and west of the foreshore and between the two outfalls are placed the storage ponds from which came the oysters which were alleged to have been the cause of the outbreaks of typhoid fever at Southampton and Portsmouth last autumn. The sewers convey slop water, surface water, and the overflow of numerous cess pits."

The next point dealt with in Foulerton's Report is the extent to which the tidal water is polluted by sewage, more especially along the main Chichester and Bosham Channels.

As we have not ourselves had the opportunity of making a detailed examination of the tidal waters of this locality and as Foulerton's results are of considerable interest not only in relation to the waters of Chichester Harbour but also in connection with the question of the pollution of tidal waters generally, and with our own observations made elsewhere on the same subject, we take the liberty of reproducing the Table given in his report, with a few trifling alterations in the manner of expressing the results so as to bring them into uniformity with similar tables given elsewhere in this Report.

CHEMICAL AND BACTERIOLOGICAL ANALYSES OF THE WATERS OF CHICHESTER HARBOUR.

(From a Report by Alexander G. R. Foulerton, F.R.C.S., D.P.H., F.C.S., &c.)

No. of Sample.	Where Sample was collected.	Approximate Distance from Mouth of Chichester Harbour.	Time when Sample was collected and state of Tide.	Date when Sample was collected.	Time of High Water at Chichester on date.	Chemical Examination.				Bacteriological Examination.	
						Parts per 1,000.	Parts per 100,000.				
							Nitrogen as :—				
						Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrates.	Number of Bacteria per C.C.	Presence or absence of B. Coli.
	1. Chichester Channel.										
1	Close to Chichester Outfall	7½ miles	1.20 p.m. (Ebb) - -	March 14th, 1903	12.44 p.m.	6·30	0·033	0·021	0·250	18,400	+
2		,,	10.25 a.m. (Flood) -	April 11th ,,	11.40 a.m.	12·05	0·0198	0·025	0·010	1,590	+
3		,,	11.45 a.m. (Ebb) - -	,, ,,	,,	13·35	0·016	0·023	0·006	620	+
4	Off Dell Quay (Mid-stream)	$7\frac{1}{16}$ miles	12.35 p.m. (Ebb) - -	March 14th ,,	12.44 p.m.	16·15	0·009	0·023	0·008	500	+
5	Off Copper Point ,,	,,	12.20 p.m. (about H.W.)	,, ,,	,,	16·80	0·020	0·036	0·004	1,270	+
6	,, ,,	,,	10. 5 a.m. (Flood) -	April 11th ,,	11.40 a.m.	16·92	0·0006	0·011	0·005	8,650	+
7	,, ,,	,,	12.12 p.m. (Ebb) - -	,, ,,	,,	17·31	0·0013	0·016	0·003	200	–
8	Birdham Creek (Inshore) -	$5\frac{10}{16}$ miles	12. 5 p.m. (Flood) -	March 14th ,,	12.44 p.m.	15·35	0·0107	0·078	0·160	9,300	–
9	Midway between West Itchenor and Bosham Channel	$4\frac{5}{16}$,,	11.20 a.m. (Flood) -	,, ,,	,,	19·40	0·0115	0·025	0·005	1,250	+
10	,,	,,	10.50 a.m. (Ebb) - -	March 24th ,,	8.57 a.m.	18·26	0·0099	0·020	0·003	1,000	–
11	,,	,,	9.40 a.m. (Flood) -	April 11th ,,	11.40 a.m.	18·75	0·0013	0·002	0·005	7,520	–
12	,,	,,	12.50 p.m. (Ebb) - -	,, ,,	,,	18·26	0·0013	0·016	0·003	190	–
13	Over Rudder Rock Oyster Layings.	3½ miles	10.30 a.m. (Ebb) - -	March 24th ,,	8.57 a.m.	18·26	0·0198	0·0395	0·004	800	–

CHEMICAL AND BACTERIOLOGICAL ANALYSES OF THE WATERS OF CHICHESTER HARBOUR.—*continued.*

(From a Report by Alexander G. R. Foulerton, F.R.C.S., D.P.H., F.C.S., &c.—*continued.*)

No. of Sample.	Where Sample was collected.	Approximate Distance from Mouth of Chichester Harbour.	Time when Sample was collected and state of Tide.	Date when Sample was collected.	Time of High Water at Chichester on date.	Chemical Examination.				Bacteriological Examination.	
						Parts per 1,000.	Parts per 100,000.			Number of Bacteria per C.C.	Presence or absence of B. Coli.
							Nitrogen as :—				
						Chlorine.	Free Ammonia.	Albuminoid Ammonia.	Nitrates.		
	2. Bosham Channel.										
14	Mid-stream close to Bosham Village, and about $1\frac{6}{16}$ miles from Junction of Bosham and Chichester Channels.	—	10.50 a.m. (Flood)	March 14th, 1903	12.44 p.m.	18·50	0·0115	0·0412	0·008	870	–
15		—	11.15 a.m. (Ebb)	„ 24th „	8.57 a.m.	16·30	0·0049	0·0132	0·003	500	–
16		—	9. 5 a.m. (Flood)	April 11th „	11.40 a.m.	16·55	0·0099	0·0198	0·006	1,030	–
17		—	1.10 p.m. (Ebb)	„ „	„	17·87	0·0013	0·0148	0·003	100	–
18	Over Bosham Deep Oyster Layings.	?	9.20 a.m. (Ebb)	March 24th „	8.57 a.m.	17·80	0·0049	0·0066	0·008	100	–
19	Close to Junction of Bosham and Chichester Channels	?	10.55 a.m. (Ebb)	„ „	„	17·78	0·0140	0·0255	0·003	500	–
20		?	12.55 p.m. (Ebb)	April 11th „	11.40 a.m.	18·65	0·0020	0·0181	0·003	70	+
	3. Emsworth Channel.										
21	Emsworth Creek off Foreshore.	$4\frac{14}{16}$ miles	12.45 p.m. (Flood)	March 17th, 1903	2.40 p.m.	11·70	0·0033	0·0082	0·010	25,000	–
22	Water from Oyster Pond, Emsworth Creek.	„	1.30 p.m. (Ebb)	„ 24th „	8.57 a.m.	2·95	0·1054	0·0247	0·080	13,700	+

Foulerton refers to these figures in some detail when considering the question of sewage contamination in its special relations to the oyster industry, but as that question has not been included in the sphere of our Report we shall merely state that he classifies the samples of the water from the Chichester and Bosham Channels as follows :—

Seriously contaminated.—All the samples taken off the Chichester sewage outfall (Nos. 1, 2 and 3) ; the sample taken off Dell Quay (No. 4) ; two of the samples taken off Copper Point (Nos. 5 and 6) ; the sample taken at Birdham Creek (No. 8) ; one of the samples taken below West Itchenor (No. 9) ; one of the samples taken close to Bosham Village (No. 14) ; and one of the samples taken off Bosham Deep Layings (No. 20).

Suspicious.—One taken below West Itchenor (No. 10) ; the sample taken over Rudder Rock layings (No. 13) ; and one of the samples taken over Bosham Deep layings (No. 19).

Pure.—One sample taken off Copper Point (No. 7) ; two samples taken below West Itchenor (Nos. 11 and 12) ; three samples taken close to Bosham Village (Nos. 15, 16 and 17) ; and one sample taken over Bosham Deep layings (No. 18).

Foulerton does not state the chemical or bacteriological standard upon which the above classification was based, but all the samples containing *B. coli* are to be found in the seriously contaminated list*, as well as three others not containing that organism, of which the purest contained 0·011 of nitrogen as free ammonia and 0·041 of nitrogen as albumenoid ammonia (No. 14). On the other hand, in the list of pure samples, one appears (No. 16) which contains as much as 0·010 of nitrogen as free ammonia with 0·020 of nitrogen as albumenoid ammonia.

An interesting section of Foulerton's Report deals with the condition of the fishing industry generally in Chichester Harbour with special reference to the influence of contamination of the tidal water by sewage, but as we have already referred to this in the section of this Report on the pollution of water in relation to its effects on fish (pp. 203–204), it will be sufficient to state here that flounders and eels have, he says, deserted the upper end of the Chichester Channel, and that in his opinion this has probably been brought about by the fouling of the bed of the harbour—owing partly to the former imperfect method of disposing of the Chichester sewage and partly to the decomposition of a species of seaweed locally called " slob." In concluding that part of his report, Foulerton advises the Local Fisheries Committee " that whatever damage may have been done in the past to the fishing industry by the discharge of imperfectly purified sewage into the harbour from the Chichester outfall works, the system which is at present being carried out is the best that is possible under the circumstances, short of a system of sewers to carry the sewage out to sea. The expense involved in the latter procedure would be practically prohibitive, and I am confident that if the new system now being carried out is efficiently supervised, as there is every reason to believe that it will be, any possible injury to fishing will be reduced to a minimum : in fact, I believe that no injury whatever will be caused."

VISIT TO CHICHESTER.

Our own visit to Chichester was made on the 22nd of August, 1904, and we desire to express our thanks to the Town Clerk and his assistant, to the City Surveyor and to Mr. John Saunders, the manager of the sewage works, for their kindness in showing us over the works, and affording us all the information and assistance that we required.

We are indebted to them for the following particulars :

The population of the city of Chichester was according to the last census (1901) 12,244, having increased from 10,808 at the census of 1891.

The city has a public water supply (thirty-five to forty gallons per head) and is sewered.

The normal flow of sewage is estimated at 400,000 gallons, but owing to the low-lying situation of the town the sewers are frequently covered with subsoil water and at times are flooded. The maximum amount of sewage and subsoil water passing during twenty-four hours to the outfall works may be taken as 3,000,000 gallons, and from November to March the average is probably about 2,500,000 gallons.

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* Although in one of these (No. 6) mere traces of free ammonia were found.

The sewage is not entirely domestic, as there is a large brewery in the city and also a large tannery, the effluent from the latter being troublesome to deal with satisfactorily.

At the Outfall Works the sewage is treated with alumina ferric and milk of lime. The normal flow and up to 1,125,000 gallons after being thus clarified is submitted to a "sprinkling" process—the beds being composed of graded shingle. In addition to the sprinkler installation, there is a set of storm-water contact beds capable of dealing with the same volume as the sprinkler, thus providing altogether for the treatment of 2,250,000 gallons. Any excess above that can be dealt with on land.

The treated effluent passes through an iron pipe across a field and discharges into a small creek forming the outlet of a brook called the "Lavant Course" which is intermittent, depending for its flow on subsoil water. The discharge of the effluent ceases about 1½ hours before the tide commences to rise at the outlet.

Having inspected the Outfall Works we visited the foreshore (at low tide) at the point where the effluent is discharged, and found it very muddy and the mud very foul below the surface.

The combined effluent and water from the brook, flow along a narrow channel 3 to 4 yards wide (at low water) for a distance of 200 to 300 yards and are there joined (at low water) by a fresh-water stream coming from an old mill.

We found very considerable quantities of *Ulva latissima* on the mud all about the outfall, but owing to the depth of this mud it was not possible for us to examine the extent of these deposits of sea weed. But sufficient was seen to render it more than probable that a serious nuisance must often occur, and it seems very probable that such nuisance in the past has been attributed directly to sewage. As far as could be judged by the eye *Ulva* was present all about the upper reaches of the Chichester Channel. Very little *Enteromorpha* was seen except in the Lavant brook where a fair quantity was found growing.

We next visited Dell Quay, the port of Chichester, and the highest point in the channel which small coasting vessels can reach.

Here we found a good deal of *Enteromorpha* of different kinds on the foreshore and some *Ulva*, but by no means so much of the latter as in the neighbourhood of the outfall. It should be mentioned that dry *Zostera marina* was also found on the shore, both here and near the outfall, but was not seen growing.

In connection with these seaweeds we may quote the following passage from Foulerton's Report:—

> "The mud is, however, only derived in part from sewage, as there is in the Harbour a very large quantity of seaweed, which contributes considerably to the fouling of the stream. From the decomposition of this seaweed a certain amount of nuisance arises because of an offensive smell; and it may be of some interest to add, this offensive smell does not arise principally from the decomposition of that species of seaweed, which is locally known as 'slob,' but is probably caused by the decomposition of another kind of seaweed, known locally as 'cabbage,' which is present in the Harbour in much smaller quantities than the slob. I have kept quantities of 'slob' and of 'cabbage' in sea water under conditions favourable to decomposition, and I find that the decomposition of the former is not accompanied by any particularly offensive odour, while the decomposition of 'cabbage' results in the evolution of extremely offensive gases, among which is sulphuretted hydrogen."

From our inquiries on the spot "cabbage" would appear to be *Ulva latissima*, but the identity of "slob," or as we also heard it termed "slub," could not be established. An old man resident at Dell Quay seemed to think that any kind of seaweed was "slub," but what the assistant Town Clerk had been given to understand as "slub" was, according to the sample produced, a variety of *Enteromorpha*. Our researches on green seaweeds have, however, shown that the latter may be quite as offensive when it putrefies in sea water as *Ulva*,* so that it is possible that "slub" or "slob" is *Zostera marina*.†

Unfortunately only a few hours were available for our visit to Chichester Harbour, and the sole examination we could make of the water was the determination of the dissolved oxygen. This we did at the outfall, in the fresh water stream a little above it, and at Dell Quay, when the following results were obtained.

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* See Section 6.

† Since writing the above Dr. Foulerton has kindly sent us samples of "slob," which we find to be *Enteromorpha intestinalis*.

No.	Where Sample was Collected.	Time.	State of Tide.	Dissolved Oxygen (c.c. per Litre at N.T.P.)
1	At outfall just beyond junction of effluent with Lavant Brook - - - - -	2.30 p.m.	Late Ebb	5·07
2	Freshwater stream from old mill above outfall - - - - - -	3.20 „	„	7·89
3	Dell Quay - - - - - -	4.30 „	„	7·80

Unfortunately we had forgotten to bring a thermometer, but the dissolved oxygen found in the fresh water stream above Dell Quay corresponds with the air saturation value for a temperature of 11°C., whereas the actual temperature was probably higher. It is quite possible that the high proportion of oxygen found may have been due to the action of *Ulva*, as we have had occasion to notice such an effect elsewhere.

E. A. L.

GENERAL CONCLUSIONS.

GENERAL CONCLUSIONS.

In framing our conclusions we desire to state that we have approached the subject entirely from the chemical and general points of view, and that the purely bacteriological aspects of the different questions involved have been left out of consideration. These latter are, no doubt, of very great importance, but we feel that they can only be done justice to by experts in the subject.

When, therefore, we use such expressions as "practically innocuous," etc., it will be understood that we do not mean that the tidal water in question is necessarily free from bacteria of an undesirable sort, but only innocuous from the chemical and general points of view. It is specially important to note this fact in connection with shell-fish.

It seems scarcely necessary to observe that in all cases of the discharge of sewage into tidal waters there are three factors of paramount importance, namely, the composition of the sewage, its amount, and the volume of tidal water available for dilution, and that the last depends not only upon the extent of the waterway, but also on the rapidity of the currents.

As regards the composition of the sewage it is obvious that the greater the concentration the more harmful are the possible effects. But of all the constituents of sewage there are good grounds for believing that in all ordinary cases the solids in suspension cause the most injurious results in tidal waters, since they not only foul the bed on which they become deposited, but act more or less as constant sources of pollution to the whole body of water flowing over them, thus leading to de-aeration. We have given several instances* of the evils which they cause.

It seems advisable roughly to classify the solid matters of sewage thus:—

(1) Floating solids such as fresh fæces, corks, straw, and other vegetable refuse, grease, matches, etc.

(2) Heavy solids.

(3) Light flocculent solids.

The following remarks may be made regarding each of these:—

(1) *Floating Solids.*

The floating matters which are always to be found in town sewage, with the exception of fresh fæces, probably do not exert any harmful effects when discharged into tidal streams. Still they give rise to unpleasant looking accumulations along the foreshore adjacent to, or in the neighbourhood of outfalls when inshore winds prevail for any length of time. As it is possible to remove them without serious difficulty from the sewage by means of screens before its discharge, we are of opinion that this should be done in all cases.

(2) *Heavy Solids.*

When sewage remains at rest, the greater proportion of the suspended solids subside in a comparatively short time,† and in our opinion it is these "heavy solids" as they may be called which are often the chief cause of the permanent mischief which follows from the discharge of crude sewage into tidal waters.

These solids together with road *detritus*, sand and silt may be carried a certain distance by strong currents, but are deposited in slack water.

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* *See* pp. 111–116.

† In special experiments carried out at Leeds on this point, it was found that nearly 70 per cent. of the total insoluble solids of crude sewage are deposited in one hour. (City of Leeds. Report on Experiments on Sewage Disposal. 1905. p. 17.)

In this way foul sludge banks are formed, which in all conditions of weather and tide, remain in a state of putrefactive fermentation, and from which masses of foul mud charged with easily oxydisable substances, such as ferrous sulphide, are often detached and floated up by the gases generated within them, and these masses becoming disseminated through the water cause its rapid de-aeration, as shown in the case of the tidal portion of the River Liffey.*

In connection with the heavy sewage solids we were much impressed by the effects produced by the removal merely of the road *detritus* from the sewage of Pembroke and Rathmines (two of the Dublin townships) before discharge from the outfall, the result being that the bed of the Liffey Estuary slightly below this point showed not even traces of fouling.†

Partly in consequence of the above considerations, as well as from the replies to the circular letter to medical officers of health of tidal localities (*see* Appendix I.), and also from our own investigations, we have formed the opinion that unless the tidal currents are exceptionally strong, and the volume of tidal water available for diluting the sewage is large in a given locality, the heavy solids of sewage and trade wastes should not be allowed to be discharged into tidal waters.

We do not think that regulations requiring the removal of floating solids and of heavy solids from sewage before discharge of the liquid matters would impose any unreasonable hardship upon local authorities, since both classes of solids could be sufficiently removed by means of suitable subsidence tanks, and screens.

(3) *Flocculent Solid Matters.*

These matters are so light that, when discharged into tidal currents even of moderate strength, they are easily carried away by them; they are moreover rapidly comminuted by the action of the waters, and become disseminated as minute particles in suspension through them; and they do not form objectionable deposits anywhere. No doubt they are eventually oxydised.

Furthermore, when the sewage is passed through screens and subsidence tanks, a large proportion of them is separated with the heavy matters. Consequently the particles which are finally discharged with the liquid sewage may usually be neglected, except when the tidal conditions in the neighbourhood of the outfall are unfavourable.

It may be well to note here that when the sewage is passed into subsidence tanks for the purpose of removing the heavy solids, it is necessary that it should be impounded for as short a time as possible, consistent with efficient settlement, otherwise the liquid matters may become putrefactive, and then when they mix with the tidal waters they will reduce the aeration of the latter too quickly. From our own observations, it would appear that a period of six hours suffices for sedimentation without inducing appreciable putrefaction in our climate.‡

As regards the quantity of liquid sewage matters which may be discharged into a tidal water, it depends upon a number of factors; the volume of tidal water available for dilution, the strength, the direction and turbulence of the currents, the position of the outfall and its proximity or otherwise to open water, and the state of the tide during discharge, whether during ebb only, or during both ebb and flood. It will be convenient to consider these factors separately, and we will deal with the position of outfalls first.

POSITION OF OUTFALLS.

Although this is an engineering question, we may perhaps be allowed to point out that it is of fundamental importance, and from our experience and observation we doubt whether, in some instances, it has received the amount of attention and study beforehand which its importance should demand.§

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* *See* pp. 283–302.

† *See* pp. 275–279.

‡ *See* pp. 181–182.

§ It has been suggested to us by a friend who is an engineer of long experience, that a good preliminary guide to the fixing of the position of a proposed outfall, before making detailed observations as to the strength of the tidal currents, etc., is the condition of the shore near the proposed site. For it may be taken as a fairly safe general rule, he says, that where a clean beach is found, the conditions are unfavourable to the deposition of sewage or other solids.

We are convinced that no outfall should be permitted which discharges crude sewage at such a point that at low tide the sewage flows either on to a stripped foreshore or into slack water.

CLASSIFICATION OF TIDAL WATERS.

As already pointed out, tidal waters may be roughly divided into three classes in relation to their capability of satisfactorily disposing of sewage matters cast into them: the first being of such nature as to dispose with complete safety of all sewage matters: the second being capable of dealing with the liquid constituents and light flocculent solids of the sewage only: while in the case of the third, some treatment of the sewage (beyond mere sedimentation)—unless it be in comparatively small quantity—must be resorted to before discharge.

A more exact definition may perhaps be given as follows :—

Class 1.—May include tidal waters, the currents of which are sufficiently strong to transport all sewage matters discharged into them, including all suspended matters, and so widely to distribute them as to render them practically innocuous before change of tide.

Class 2.—May include tidal waters, the currents of which can transport the liquid sewage matter and flocculent solids (not heavy solids) discharged into them, and so widely to distribute them as to cause sufficient dilution to render them practically innocuous before change of tide.

Class 3.—Includes all other tidal waters which are not so favourably circumstanced.

Only those tidal waters with exceptionally strong currents and with comparatively large volumes of tidal water available for dilution can be placed in the first class, since the currents must be strong enough to transport the heavy solids some distance away from the outfall, or to wash them thoroughly from adhering sewage matters before they can subside to the bottom, and still more widely to distribute the lighter solids and liquid sewage matters so as to dilute them sufficiently to render them innocuous before being carried back by the return of the tide.

When so diluted the sewage matters undergo fermentative change so slowly that they exert no appreciable reducing effect upon the aeration of the water with which they become mixed.

In many cases the question whether a tidal water should be placed in the first or second class must depend upon the volume of sewage daily to be discharged into it. At Newport,* Monmouthshire, for instance, we found that although all the crude sewage was being discharged into the River Usk at all states of the tide and was apparently being satisfactorily disposed of in that way, still there was evidence to indicate that the quantity of crude sewage had nearly reached the maximum limit allowable, and that it would in all probability be found in future that it would be necessary first to separate the solid matters, or possibly to restrict the discharge to the ebb tide, in the event of the quantity of sewage becoming materially increased with the growth of the town.

In like manner there are some tidal waters so favourably circumstanced for the disposal of *liquid* sewage matters, although not so for heavy solid matters, that there can be no doubt as to their being placed in the second class, for example, the deep water channel of the Estuary of the Liffey. While in other cases it must depend upon the volume of sewage discharged, whether they be placed in the second or third class.

MAXIMUM QUANTITIES OF SEWAGE DISCHARGEABLE INTO TIDAL WATERS WITHIN LIMITS OF SAFETY.

A number of experiments have been described (in Section 1) as to this, which show that the dissolved oxygen in mixtures of sea or fresh water with from 1 to 5 per cent. of the liquid matters of ordinary town sewage † is not completely absorbed when the mixtures are kept out of contact with the air for forty-eight hours at ordinary temperatures.

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* *See* pp. 383–388.

† It should be noted that by "liquid sewage matters" crude sewage is meant from which all suspended solids, except colloidal substances, have been removed by screening and subsidence.

It must, however, be recollected that in polluted waters freely exposed to air, side by side with de-aeration (caused by the polluting matters present), re-aeration (from the atmosphere) occurs, and that the maximum rate of re-aeration from our experiments would appear to be 2·5 c.c. of oxygen per litre of water per forty-eight hours under calm weather conditions when the tidal water is composed of about equal proportions of sea and fresh water, and at a slightly greater rate with larger proportions of sea water.

It may, therefore, be assumed, we think, with some confidence that fresh liquid sewage may be safely discharged into third class tidal waters to an extent which shall not exceed at any time 5 per cent. of the diluting water except within a few yards of the outfall, where it might be slightly greater.

If the sewage to be disposed of materially exceeds this proportion, it ought to be submitted to purification by means of contact beds or percolating filters.

Larger proportions of sewage may obviously be discharged into tidal waters of the first and second classes, especially when the discharge is limited to the ebb tide. But we do not think that the quantity should exceed 10 to 15 per cent. of the tidal waters with which it becomes mixed under calm weather conditions, except in the immediate neighbourhood of the outfall.

It must be remembered that we do not mean by the expression "diluting water," the entire flow of river and tidal water, but simply those portions of them with which the liquid sewage matters become mixed by the time they have reached a reasonable distance below the outfall, in calm, dry weather. In the discussion of the question of standards, which will be found in Section 1, pp. 91 to 96, it is suggested that 200 yards should be taken as a reasonable distance from the outfall; and it is shown that in the case of an existing outfall, the relative volumes of liquid sewage from it, and of the "diluting water" with which it becomes mixed, be ascertained without difficulty by suitable methods, within this range in calm weather.

In the case, however, in which an outfall does not exist, but a site for one is proposed, the diluting power of the waters maybe roughly gauged by discharging into them a strong solution of eosin, or of other suitable colouring matter, near the selected position, in calm weather, and collecting samples along the path taken by them. The degree of dilution of the colouring matter in these samples may be approximately estimated by comparing them with dilutions of the original solution of known strength.

If it be impracticable to estimate the probable volume of "diluting water" in this, or in any other way, and it becomes necessary roughly to calculate the capacity of given tidal river to deal with a given sewage, from its entire flow compared with that of the sewage, then the proportion of 5 per cent. of liquid sewage as above suggested as an allowable limit, would be too high; it should not, in our opinion, be allowed to exceed 1 per cent. of the entire flow *at low water*, unless, of course, the sewage be more thoroughly purified than is possible by simple subsidence and screening.

Effects of the Discharge of Sewage into Tidal Waters on Fish (*Pisces*).

No case has come under our own notice of any injury caused to sea fish, or the sea fishing industry, by the discharge of sewage into tidal waters, and we question whether such injury is ever likely to occur to a serious extent.*

But on the other hand there can be no question that extensive damage has been done to the migratory *Salmonidæ* in the estuaries of certain rivers by the discharge into these latter of either crude or imperfectly purified sewage.

It is probable that in such cases the damage is chiefly due to de-aeration. Serious damage may also be caused by sewage solid matters being brought down in a state of putrefaction by freshets from the upper reaches of highly polluted rivers to tidal waters, as was pointed out when describing the River Ouse in the neighbourhood of its junction with its tributaries the Aire and Don, and just above the Humber.

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* As already stated (p. 203) Foulerton came to the conclusion that formerly the flounder fishing had been damaged in Chichester Harbour by the discharge of the imperfectly purified sewage from Chichester. He however states that the foul mud which formed deposits in the upper part of the channel and destroyed the breeding grounds, was in part derived from decaying seaweed.

Such a state of affairs must be seriously prejudicial to the ascent of salmon, and we see no reason why it should be allowed to continue.

For it is not only possible but comparatively speaking easy to treat sewage in such a way that the solid matters may at least be removed before the discharge of the sewage into rivers. This being the case, we are of the opinion that a very great improvement can eventually be effected in the condition of our more polluted salmon rivers; and we are under the impression that in some of these—the Ribble and some of its tributaries, for instance—the improvement has already commenced.

STANDARDS OF IMPURITY.

The effects possibly produced by the pollution of tidal waters by sewage and trade wastes, may, we think, be classified as follows :—

1. Injury to navigable channels by the formation of deposits which have to be removed from time to time by dredging.

2. Injury to fish and the fishing industry, by the introduction of substances into the water which are either toxic to fish, or deprive it of dissolved oxygen.

3. Production of nuisances, which may be :—

a.—Of a general kind in the æsthetic sense arising from such causes as unpleasant smells, unsightly deposits, such as foul mud banks, etc., and interference with the pleasure of bathing.

b.—Of a general kind in the public health sense, caused by the inhalation of foul gases, and possibly in other ways.

c.—Of a definite kind in the public health sense by the diffusion of the specific organisms of certain diseases, of which typhoid fever is probably the most important, and this more particularly, but by no means entirely in connection with the contamination of shell fish.

d.—Indirect, but also of importance from the public health point of view, by the growth and subsequent decay of certain green seaweeds.

It is obvious that standards based on general and chemical grounds which might reasonably be applied in 2, 3*a.*, and probably 3*b.* also, would by no means necessarily meet the cases of 3*c.* or 3*d.*

3*c.* involves questions mainly of a bacteriological character, and as already stated we do not profess to be in a position to deal with them. It seems evident from the first section of this Report that standards formulated with the view of regulating the discharge of sewage and trade washes into tidal waters in order to avoid the possible effects mentioned above, with the exception of 1, 3*c.*, and 3*d.*, must be based on some form of aeration test. This subject has already been discussed as fully as our present knowledge has permitted.* Much work has yet to be done, however, before the question of standards can possibly be regarded as definitely settled. But the standards which have been suggested are based upon the most accurate information so far obtainable, and we believe that they will form a satisfactory basis, not only for the guidance of local authorities and professional men, but also for further investigation. It need scarcely be pointed out that the standards must vary at least to some degree for every locality if local authorities, on the one hand, are to be allowed to take every legitimate advantage of the favourable conditions which their tidal waters may present for the disposal of the sewage of their localities, and if, on the other hand, the interests of the public health and of fish life are to be safeguarded.

Regarding 1, and the extent to which the suspended solids should be removed from sewage prior to its discharge into tidal waters, we have already expressed our views (*see* pp. 425–426).

Regarding 3*d.* we append a special paragraph.

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* We may specially note that one of the chief difficulties which has hitherto stood in the way of formulating standards, viz., the want of a precise and simple method for determining the rate and total absorption of atmospheric oxygen by a given sewage, or sewage effluent, has been entirely surmounted. We have dedescribed a method (*see* pp. 101–105) which is capable of effecting these determinations with accuracy, and in a simple manner.

AVOIDANCE OF NUISANCES CAUSED BY CERTAIN GREEN SEAWEEDS, AND INDIRECTLY BY SEWAGE.

Abundant evidence has been given in this Report* to show that an extensive nuisance has occurred in several tidal localities from the growth in large quantity and subsequent decay of certain green seaweeds, of which *Ulva Latissima* is the most important, and also that this growth is caused by the pollution of the water by sewage.

The question as to how such a nuisance can best be avoided has also been discussed at some length in this Report,† and it has been shown that the main objects to be aimed at are: (1) The removal of free ammonia from the sewage; (2) the separation of the sewage solids, which slowly evolve ammonia when submerged in water; and (3) the avoidance as far as possible during the purifying processes of the formation of nitrates, or, as an alternative, their destruction.

And it is further shown that these objects are best attained by the following three consecutive operations:—

First Stage.—Removal of road detritus (by catch-pits), gross solids (by screening), and the greater portion of the suspended solids (by sedimentation).

It is possible that from two-thirds to three-quarters of the total of the above mentioned solids will be got rid of by the process named, and that the effect in relation to the ammonia will be a purification of 17 to 20 per cent.

Second Stage—Treatment of the sedimented sewage by sprinkling filters, followed by a brief period of sedimentation. This brings about: (*a*) The removal of the remainder of the suspended solids; (*b*) the removal of free ammonia; (*c*) the production of nitrates.

It is somewhat difficult to give a definite statement as to the degree of purification to be expected from this method of treatment, but the mean of all the different experiments made shows a total of about 70 per cent.

Third Stage.—Treatment by denitrefication. This will probably induce a further purification of 10 to 12 per cent., or a total of 80 to 82 per cent. of those factors, namely, ammonia and nitrate, which contribute to the growth of the seaweeds.

Whether any or all of these operations may be necessary in a given locality must depend upon the magnitude of the nuisance, and the particular conditions existing in the locality.

Thus at Belfast, where the nuisance has for years past been of a very acute and extensive nature and as a consequence the city is under statutory obligations to purify its sewage to the satisfaction of the Local Government Board, one of us has felt it to be his duty to advise that all three operations shall be carried out, in spite of the heavy cost of the purifying plant.

But in other localities where the nuisance is less extensive it might be more economical to resort to the first operation only, namely sedimentation, and to remove the deposits of seaweed as they are washed ashore.

We should like to repeat, in drawing our Report to a conclusion, that we have endeavoured to make it as complete as possible, so that it shall be a useful statement of our present knowledge of the pollution of tidal waters for the information of the Rivers Boards which the Commission has recommended in their Third Report (1903) should be established, together with a Central Body for controlling the discharge of sewage into waterways.

We should also like to repeat that there are still many questions in connection with the pollution of tidal waters which require investigation, and to point out that this will probably prove to be of a very laborious nature. It need scarcely be contended that the precise formulation and enforcement of standards, such as we have suggested, must of necessity be referred to specially constituted authorities of the kind recommended by the Commission.

W. E. ADENEY.
E. A. LETTS.

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* *See* Section on Nuisances caused by Green Seaweeds, pp. 141–168.

† *See* Section on the Effects of Different Methods of Sewage Purification, pp. 171-197.

ADDENDUM TO SECTION 1.

THE RELATIVE CAPACITIES OF FRESH WATER AND OF SEA WATER TO BEAR POLLUTION WITHIN LIMITS OF FOULING.

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THE RELATIVE CAPACITIES OF FRESH WATER AND OF SEA WATER TO BEAR POLLUTION WITHIN LIMITS OF FOULING.

Much uncertainty appears to exist on this subject at the present time. At first sight it would seem safe to assume that fresh water must possess an advantage over sea water as regards the capacity of bearing pollution without being fouled, since it can hold a decidedly larger quantity of oxygen in solution than sea water, temperature for temperature. But against this must be considered the property which sea water has been found to possess of more rapidly transmitting dissolved atmospheric gases from the surface exposed to the air in a vertical direction downwards than fresh water.* There is, moreover, no certainty that water bacteria would be equally active in fresh water and in water containing so much saline matter as sea water. On the contrary Purvis and Coleman believe from observations which they have made that sea water exerts a very marked retarding effect on nitrogen fermentation ; † while in America it appears to have become accepted that it has an accelerating effect upon carbon fermentations.‡

The impression that over-polluted sea water becomes much more offensive than over-polluted fresh water also seems to be widespread.

(a) *The Relative Rates of Absorption of Dissolved Oxygen by Sewage Matters in Fresh Water and in Sea Water.*

Such experiments as have been made in connection with this question appear to indicate that the rate of fermentative changes in sewage matters, and consequently the rate of absorption of dissolved oxygen by them, is very considerably influenced by the character of the waters with which they become mixed, and it has been concluded from them that sea water exercises an accelerating effect upon the carbon-oxidation stage of fermentation of the sewage matters, and a retarding influence on the subsequent nitrogen-oxidation stage, as compared with fresh water.

The experiments referred to have not, however, been sufficiently numerous, nor extended in scope, to warrant very definite conclusions to be drawn from them. The methods of study employed in them are, moreover, open to criticism. The subject is obviously one of great importance in connection with the problem of the protection of tidal waterways from over pollution, and requires a much more extended investigation than has so far been given to it.

We have made a few experiments on the subject by means of the modification of the aeration method which will be found described in Section 1, p. 103, of this Report. We give a description of these experiments, and of the results obtained, in the succeeding paragraphs. They do not, it will be found, support the conclusion just given. Time unfortunately has not permitted us making an exhaustive study of the subject.

An average sample of sewage was collected from the main sewer of Belfast on November 29th last, and immediately forwarded to Dublin in a completely filled bottle. On the next day it was opened and mixed with a little magnesium hydroxide to fix the free carbon dioxide, and allowed to stand for a short time. It was then decanted from the heavier solids. Portions of the decanted liquid, immediately after being well stirred, were mixed with distilled water and with sea water§ in proportions of 20 per cent., and 1,000 c.c. of each mixture were put into a 1,500 c.c. fermentation flask attached to a standard pressure flask of similar capacity, as described in Section 1, p. 103. 1,000 c.c.

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* *See* Section 1, of this Report, pp. 56–66.

† The Influence of Sea Water on the Decomposition of Sewage, *Journ. Royal Sanitary Institute*, 1906, p. 433. *See* also Dr. Fowler's "Observations on the Effect of the Discharge of Septic Tank Sludge into a Tidal Estuary," Appendix to this Report, p. 555.

‡ *See* the Report by the Charles River Dam Committee upon the advisability and feasibility of building a dam across the Charles River at or near Craigie Bridge. Boston : Wright and Potter Printing Company.

§ The sea water was collected in Dublin Bay. It had been kept in a large glass-stoppered bottle for some time previous to use in these experiments. It contained 1,970 parts chlorine per 100,000.

of the undiluted sewage were also put up in a fermentation flask attached to standard pressure flask. The three fermentation flasks with their attached pressure flasks were put into a mechanical shaker, and their contents kept gently shaken, and maintained at temperatures from 15° C. to 18° C. The volume of oxygen absorbed from the atmosphere of each fermentation flask was from time to time determined by replacing it with a known volume of oxygen, in the manner described on p. 104. The results obtained are recorded in the following table :—

TABLE A.—The Rate of Absorption of Dissolved Oxygen by Sewage and by Mixtures of the same Sewage with Sea Water and with Distilled Water, in Proportions of 20 per cent., when kept, enclosed with an excess of Air, in Fermentation bottles at 15° to 18°C., and in gentle motion (*Adeney*).

NOTE.—The Free Carbon Dioxide in the Sewage and in the Mixtures was fixed by the addition of Magnesium Hydroxide. The Volumes of Oxygen are expressed in cc. at N.T.P. per 1,000 cc. of Sewage or Mixture.

——	Sewage.		Mixtures of 20% Sewage with—			
			Sea Water.		Fresh Water.	
	Total oxygen absorbed.	Oxygen absorbed per 24 hours.	Total oxygen absorbed.	Oxygen absorbed per 24 hours.	Total oxygen absorbed.	Oxygen absorbed per 24 hours.
At end of—						
1st day	51·5	51·5	5·8	5·8	5·8	5·8
2nd day	86·5	35·0	14·9	9·1	15·9	10·1
3rd day	106·6	20·1	19·8	4·9	20·4	4·5
4th day	115·4	8 6	22·7	3·9	24·9	4·5
5th day	119·7	4·3	24·3	1·6	25·9	1·0
6th day	123·2	3·5	25·9	1·6	26·5	0·6
7th day	126·4	3 2	27·4	1·5	27·4	0·9
8th day	129·7	3·3	28·5	1·1	28·5	1·1
10th day	136·1	3·2	30·2	0·9	30·3	0·9
16th day	148·8	2·1	34·2	0·7	34·3	0·7
19th day	155·8	2·3	36·3	0·7	35·6	0·5
26th day	177·3	3·3	41·5	0·7	42·4	0·9
29th day	181·7	1·5	43·4	1·0	46·9	1·5
34th day	197·2	3·1	48·1	0·9	54·1	1·4
42nd day	232·0	4·4	58·0	1·2	61·5	0·9
47th day	—	—	61·9	0·8	64·7	0·4
48th day	254·4	3·7	—	—	—	—
53rd day	263·8	1·9	—	—	—	—

The foregoing figures show that the rates of absorption of oxygen by the polluting matters in the two mixtures were substantially the same. They varied slightly during the course of fermentation, the rate being alternately a little more rapid, first in the fresh water mixture, and then in the sea water mixture. But after the seventh day they became similar and remained so up to the twenty-sixth day, when they again varied to a slight extent, until at the conclusion of the experiment the volume of oxygen absorbed by the polluting matters in the sea water and fresh water amounted in all to 61·9 c.c., and 64·7 c.c., oxygen per litre, respectively, at the initial temperature and pressure that occurred at the commencement of the experiments.

According to the principle of the method of experimenting, the composition of the gases of the atmospheres in the fermentation flasks at the conclusion of the experiments should be similar to that at the commencement, allowing for experimental errors, and in order to check this point, the volume and composition of the gases in the atmosphere of each fermentation bottle were determined at the commencement and at the conclusion of the experiments. The volumes were as follows, calculated to 0°.C., and 760 mm. bar :—

——	Sewage Bottle.	Sea Water Bottle.	Fresh Water Bottle.
	c.c.	c.c.	c.c.
At commencement—			
Total volume of gases	445·3	419·8	441·2
Carbon dioxide	0·0	0·0	0·0
Oxygen	93·5	88·2	92·7
Nitrogen	351·8	331·8	348·5
At conclusion—			
Total volume of gases	442·2	418·6	440·2
Carbon dioxide	0·0	0·0	0·0
Oxygen	86·4	84·5	88·8
Nitrogen	355·8	334·1	351·4

These results are as concordant as could be expected considering the experimental errors attending such measurements.

It will be observed from them that, at the conclusion of the experiments, the volumes of oxygen had slightly decreased, but that those of nitrogen had increased to nearly equivalent degrees. The increase of nitrogen in each case may be ascribed to the fact that the oxygen which was passed into the fermentation bottles from time to time to replenish that which was absorbed, contained small quantities of nitrogen. This would give rise to an equivalent decrease in the oxygen. Thus the increase of nitrogen and the greater part of the decrease of oxygen may be accounted for ; one compensates the other, and they do not, therefore, appreciably affect the final results obtained.

A further slight loss of oxygen in the atmosphere of these bottles was also to be anticipated from the employment of indiarubber corks in making the necessary fittings to the bottles. But care was taken to use corks of the same size, so that the effect on the atmospheres of the fermentation bottles would neutralise their effect on the atmospheres in the pressure bottles.*

The atmosphere of one of the pressure bottles employed in the above experiment was carefully examined to ascertain the exact loss of oxygen it had suffered. The loss was found to amount to 3·0 c.c. after the bottle had been in use for forty-seven days.

As regards the character of the fermentations that went on during the experiments recorded in Table A, it is shown by the succeeding Table B, that both the carbon and nitrogen stages of fermentation had been completed in the mixtures by the time the experiments were stopped, and nearly so in the undiluted sewage.

TABLE B.—Nitrogen Compounds in the Mixtures employed for the Experiments recorded in TABLE B, expressed in parts per 100,000.

——	Sewage.	Sea Water Mixture.	Fresh Water Mixture.
At commencement—			
Nitrogen as ammonia	0·825	0·165	0·165
Nitrogen as nitrites	0·0	0·00	0·00
Nitrogen as nitrates	0·0	0·01	0·01
Organic nitrogen	0·675	0·135	0·135
At conclusion—			
Nitrogen as ammonia	0·02	0·0	0·0
Nitrogen as nitrites	0·0	0·14	0·0
Nitrogen as nitrates	0·92	0·0	0·142
Organic nitrogen	0·5	0·072	0·076

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* Since these experiments were made, it has been found that ordinary corks, previously soaked in melted paraffin may with advantage be substituted for india rubber corks.

For the reasons given in Section 1 of this Report, p. 44, it will be seen that the volume of oxygen absorbed during the nitrous and nitric fermentation in the respective mixtures may be calculated from the following equations :—

$$(1)\ 2NH_3 + 3O_2 = N_2O_3 + 3H_2O.$$
$$(2)\ 2NH_3 + 4O_2 = N_2O_5 + 3H_2O.$$

The quantities of nitrous and nitric nitrogen which were found in the two mixtures are given in Table B, they were 0·14 and 0·142 parts per 100,000 respectively. These amounts are respectively equivalent to 3·4 c.c. and 4·5 c.c. oxygen, according to the above equations. If then the nitrogen fermentation in the sea water mixture had been wholly nitric instead of nitrous, the volume of oxygen it would have absorbed would have been increased by 1·1 c.c., and this would have brought the total volume up to 63·0 c.c. When this is compared with the volume absorbed by the fresh water mixture, viz., 64·7, it must be admitted that both during fermentation and on completion of the fermentation, the volumes of oxygen absorbed were so nearly alike that they may be taken for all practical purposes as similar.

The results of these particular experiments show that the conclusion put forward by the chemist to the Charles River Dam Committee,* viz., that the dissolved oxygen disappears very much more rapidly in mixtures of sewage and salt water than in mixtures of the same sewage, and of similar strength, with fresh water, cannot be taken as having been generally proved. On the contrary, they show that there was no practical difference in the rate of carbon fermentation in the sewage matters employed, whether they were mixed with fresh or with sea water. They also show that, under the particular conditions of these experiments, there was no marked retardation of nitrification in the sea water, as compared with that in the fresh water. The only difference shown by the two mixtures was that in the fresh water the nitrogen fermentation was wholly nitric, while in the sea water it was wholly nitrous. As already stated, Purvis and Coleman have published the results of some experiments, from which they have concluded that sea water exerts a retarding effect upon nitrification. They however employed quite an exceptionally strong sewage for their experiments, and it is possible that the retardation which they noticed was due rather to this fact than to the effect of the sea water.

The experiments which are recorded in Table A., may however be objected to on the ground that the addition of magnesium hydroxide introduces a disturbing factor in the question. In order to meet this objection, a second series of experiments, precisely similar in every respect, except that the employment of magnesium hydroxide was avoided, was made with a fresh sample of Dublin sewage. The following results were obtained :—

TABLE C.—Rate of Absorption of Dissolved Oxygen by Sewage and by Mixtures of the same Sewage with Sea Water and with Distilled Water, in proportion of 20 per cent., when kept enclosed with an excess of Air in Fermentation Flasks at 15° to 18° C., and in gentle motion (*Adeney*).

NOTE.—No precautions were taken to fix free Carbon Dioxide by the addition of Magnesium Hydroxide.

———	Sewage.		Mixtures of 20 % Sewage with—			
			Sea Water.		Fresh Water.	
	Total oxygen absorbed.	Oxygen absorbed per 24 hrs.	Total oxygen absorbed.	Oxygen absorbed per 24 hrs.	Total oxygen absorbed.	Oxygen absorbed per 24 hrs.
At end of—	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
1st day - -	26·5	26·5	12·2	12·2	9·5	9·5
2nd „ - -	37·0	10·5	16·0	3·8	12·0	2·5
3rd „ - -	42·3	5·3	17·5	1·5	13·5	1·5
4th „ - -	47·8	5·5	18·9	1·4	14·6	1·1
5th „ - -	50·8	3·0	20·2	1·3	15·5	0·9
6th „ - -	53·1	2·3	21·3	1·1	16·7	1·2
7th „ - -	55·8	2·7	22·4	1·1	17·6	0·9
8th „ - -	58·0	2·2	23·6	1·2	18·7	1·1
10th „ - -	62·2	2·1	25·1	0·8	20·3	0·8
12th „ - -	66·1	2·0	26·3	0·6	21·5	0·6
20th „ - -	76·8	1·2	28·2	0·2	25·8	0·5

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* *Ibid.*, pp. 77 and 270.

On determining the volume of the gases left in each fermentation bottle at the conclusion of these experiments, and analysing a portion of them, the following results were obtained :—

——	Sewage Bottle.	Sea Water Bottle.	Fresh Water Bottle.
	c.c.	c.c.	c.c.
Total volume of gases	410·6	430·4	414·9
Carbon dioxide	17·4	3·2	5·2
Oxygen	67·6	86·0	80·4
Nitrogen	333·5	343·3	332·3

It will be seen from these results that carbon dioxide was present in the atmosphere of each bottle, and that it must be corrected for in estimating the true absorption of oxygen by the polluted waters. The corrected volumes of oxygen absorbed by the sewage, and by the two mixtures are :—

Sewage	94·2 c.c.
Sea water mixture	31·4 ,,
Fresh water mixture	31·0 ,,

These last figures show that the average rate of absorption of oxygen at the end of the 20th day of observation was practically similar in the two mixtures. The figures for the first two days indicate a rate in favour of the sea water, but they cannot be taken as correctly indicating the relative rates of absorption in the two mixtures during that period, since they are possibly masked by unequal evolution of carbon dioxide from the two mixtures into the respective atmospheres enclosed with them in the fermentation bottles. This is probable, because the fresh water employed in these experiments was exceedingly soft, namely, distilled water, and therefore, unlike the sea water, contained practically no saline matters with which the carbon dioxide in the sewage could form bi-carbonates.

After the second day, when no doubt an equilibrium had been established between the tension of the carbon dioxide in the atmsophere and in solution in each fermentation bottle, the rate of absorption of oxygen appears to have been practically equal, and it was no doubt so, since the evolution of carbon dioxide from the two mixtures into their respective atmospheres would be similar under the conditions of the experiments, after the above equilibrium had once been established, so long as the rate of absorption of oxygen was equal in the two mixtures.

It must be concluded from the two foregoing series of experiments that the rates of carbon fermentation and of nitrogen fermentation in sewage matters employed were practically unaffected, whether the sewage matters were mixed with sea water or with fresh water, and kept under the given conditions, and at temperatures between 15° and 18° C.; and that also the rates of absorption of oxygen by the sewage matters were similarly unaffected.

It cannot be taken as generally proved, therefore, that fresh water possesses any superiority over sea water in its capacity of bearing pollution within limits of fouling. It is true that fresh water can hold 20 per cent. more oxygen in solution than can sea water, temperature for temperature, under natural conditions, but against this must be considered the fact that dissolved oxygen is transmitted through de-aerated sea water, from the surface downwards, about three times more quickly than through de-aerated fresh water.*

(b) *Comparative Offensiveness of Over-polluted Sea Water and Fresh Water.*

It has already been remarked that there seems to be a widespread impression that the odours from over-polluted sea water are more offensive than those from over-polluted fresh water. This impression is probably well-founded, since sulphides, and possibly organic sulphur compounds, are formed in sea water, when over-polluted by the reduction of its sulphates.† We have not, however, observed any offensiveness from sea water when polluted within limits of fouling, that is, so long as dissolved oxygen is present in it; any more than we have from fresh water, when pollutedwithin similarly restricted limits.

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* Section 1, p. 63, Nos. 8. 9 and 10.
† *See* p. 120.

2. Influence of Dilution on the Rate of Absorption of Oxygen by Sewage Matters.

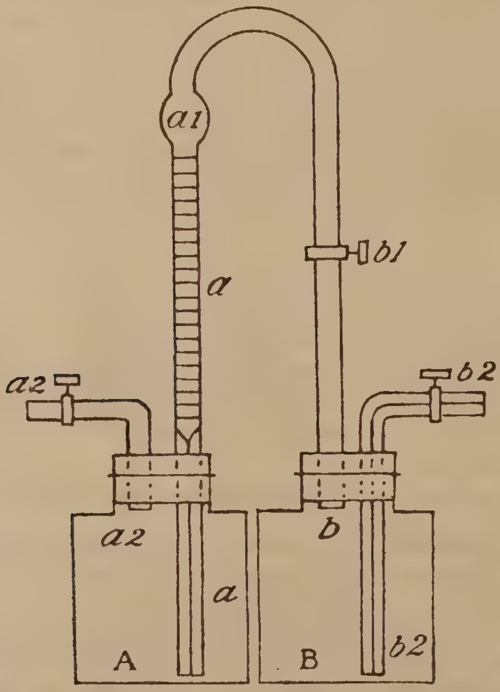
The results of the experiments with the undiluted sewages, which are recorded in Tables A, B, and C, have not so far been referred to in detail. They were included with the other results recorded in same tables because they afford some evidence on the question of the influence of dilution on the rate of absorption of oxygen by sewage matters. This question has already been dealt with to some extent in Section 1 of this Report, p. 72 and 74, and it has been shown that, when after dilution the proportion of sewage matters becomes small, from 10 to 5 per cent., it exerts a retarding effect on the rate of absorption ; but that when after dilution the proportion is larger, from 10 to 20 per cent., it does not appreciably affect the rate of absorption, at least during the first twenty-four hours, and when the supply of oxygen is limited to that dissolved in the mixture of water and sewage.

The experiments recorded in Table A show very clearly however, that when the proportion of sewage remains large after dilution, 20 per cent. in these experiments, and when both the undiluted and diluted sewage matters are kept in gentle motion in contact with a large supply of air, the rate of absorption of oxygen by the sewage matters is very distinctly retarded by dilution for a short time, but that subsequently the retardation is not in proportion to the dilution.

Thus the experiments with the undiluted sewage show that the absorption of oxygen by it at the end of the first day was nearly ten times greater than in either mixture. At the end of the third day, however, it was only four times greater, and during the succeeding days it was only from two to three times greater, and that finally the fermentation of the diluted sewage matters was completed in a shorter time than that of the undiluted sewage matters.

3. Improved Form of Apparatus for Observing the Rate of Absorption of Oxygen by Polluted Waters.

Further experience with the simple modification of the aeration method which will be found described in Section 1, p. 101, has led to a considerable modification and simplification of the apparatus employed. The form now used by the author is shown by the accompanying diagram.*



The bottles A. and B. are two flat and shallow bottles of similar capacity. Each bottle is fitted with an ordinary cork previously soaked in melted paraffin. Through the cork of A. passes a capillary glass tube to the bottom of the bottle. This tube is continued above the cork by a graduated one of wider bore, the upper end of which is enlarged to a small bulb, *a*1, and then bent downwards as shown in the diagram, and continued downwards until it passes through the cork of the second bottle B, at *b*; it is furnished with a glass stopcock, *b*1, just above the cork of B. By means of this connecting tube, *aa*, and stopcock, communication between the two bottles can be opened or closed at will. The cork of the bottle A is also fitted with a short tube and stopcock, *a*2. The cork to the bottle B is likewise furnished with a second tube and stopcock *b*2. It is a capillary tube and passes to the bottom of the bottle.

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* *See* Scientific Proceedings of the Royal Dublin Society, Vol. XI., 1908.

To work the apparatus, the bottle B is partially filled with a known volume of the polluted water, previously mixed with a little magnesium hydroxide to fix free carbon dioxide, and a similar volume of distilled water is poured into the bottle A. As the two bottles are similar in capacity, the volumes of the air spaces left in them are also similar one to the other. The polluted water and distilled water should have been left in the laboratory for some little time previously to allow of them assuming a common temperature. The plug of the stopcock *b*1 is taken out, and the stopcock *a*2 is closed, and *b*2 is opened. The two corks are then inserted into their respective bottles, and the whole apparatus is put aside for a few minutes to ensure their contents assuming the same temperature as that of the laboratory. This is noted, and also the height of the barometer. The effect of keeping the stopcock *a*2 closed during the operation of inserting the corks into their respective bottles, as above described, will be found to cause a rise of the water through the capillary tube *a* and above the zero point of the graduated portion immediately above it. This stopcock is now cautiously opened to allow of the water in the graduated portion of the tube to sink back to the zero point; it is then closed. The stopcock *b*2 is also closed, and the plug of *b*1 is replaced.

The pressure in B will be that of the atmosphere, and in A that of the atmosphere *plus* that due to the column of water in the capillary tube *a*, less the height to which the water rises in it by capillary action. If the polluted water be a strong one, the apparatus is put into a mechanical shaker, and the contents of the two bottles are kept in gentle motion. If, however, it be a weak one, this will be unnecessary; an occasional shake of the two bottles will be sufficient. The apparatus should be kept at a temperature of about 15° to 18° C.

The principle on which the apparatus works depends upon the fact that the atmosphere in the bottle A remains practically unchanged in composition during the time of the experiment, and the bottle A consequently acts as a standard pressure bottle. As the oxygen is absorbed from the atmosphere in the bottle B, the pressure of the atmosphere will be reduced in direct proportion to the loss of oxygen, as no carbon dioxide will be evolved from the polluted liquid owing to its fixation by the magnesium hydroxide previously added.* If, therefore, the stopcock *b*1 be opened, the water will rise above the zero of the scale of the tube *aa* in proportion to the loss of pressure in B. The volume of water which so rises into the graduated portion of the tube *aa*, at any given time, and the height of it above the zero mark, give the means of calculating the volume of oxygen absorbed by the polluted water in B., during the period of observation, thus:—

Let v' = volume of oxygen absorbed from atmosphere in B, at initial temperature and pressure.
V = volume of air in A or B at commencement.
v = volume of water that rises above the zero of the scale of the tube *aa*.
p' = height of water in the capillary tube *a* above the level it assumes by capillary action.
p'' = height of water in the graduated tube above the zero mark on the scale.
$p = p' + p''$.
P = pressure of air in B at commencement, in terms of the water barometer. The pressure in A at commencement will be $P + p'$.

$$\text{Then } v' = 2v + \tfrac{p}{P}\,V - \tfrac{p'}{P}\,(V - v).$$

---

* If crude sewage be the subject of examination, it should be diluted to five or ten times its volume with tap water, before being placed into B, such dilution prevents the evolution of nitrogen to an appreciable extent into the atmosphere of the bottle B, which might otherwise occur if the sewage were examined in the undiluted conditions, since crude sewage is generally super-saturated by free nitrogen.

Since v is generally small in comparison with V, it may be neglected, except in cases where the utmost accuracy is desired. The equation then becomes :—

$$v' = 2v + \frac{p''}{P}V$$

The reason for adjusting the level of the water at the zero of the scale at the top of the capillary portion of the tube *aa*, at the commencement of the experiment, will be understood from the last equation. It is evident from it that, if this were not done, a considerable absorption of oxygen would take place from the atmosphere of bottle B. before the water in the tube *aa* would rise to the graduated portion of it. It may be here remarked that it is inconvenient to have the graduated portion of the tube *aa* inside the bottle A. owing to the difficulty of reading the scale when it is so placed.

As regards the dimensions of the apparatus these must be varied to meet the object for which the apparatus is required. Whether, for instance, it is required :—(1) to control the pollution of waterways, for safeguarding the interests of public health, or of fish life, within standards such as those suggested in Section 1, p. 91 ; (2) to determine the quality of an effluent from a continuous filter bed or from a contact bed ; (3) to determine the strength of a sewage in a comparatively unpurified condition, *e.g.*, tank liquor.

An apparatus capable of indicating very small volumes of absorbed oxygen such as would be required to be observed for the first of the above objects and at the same time capable of permitting the use of volumes of polluted water sufficiently large for subsequent chemical analysis, if such be necessary, should be as follows :—A and B should each have a capacity of 1,200 c.c. which permits the use of 1,000 c.c. of polluted water, and provides for an air space of 200 c.c. The capillary portion of *aa* should be as short as possible in all forms of the apparatus. The bottle should consequently be made as shallow as possible. The graduated portion should have a capacity of 3 c.c., and its fine divisions should give readings in 1/20th c.c. The tube would then be about 112 mm. long and 5.5 mm. bore. The volume of the bulb *a*1 should be about 1 c.c.

The total loss of oxygen in the atmosphere of B observable by means of an apparatus of these dimensions would slightly exceed 10 c.c. per litre of water, without replenishing the oxygen absorbed in B. by fresh oxygen in the manner to be described later on.

The dimensions of an apparatus required for the second purpose would be such that A and B should each have a capacity of 1,500 c.c., and would allow of the employment of 1,000 c.c. of the polluted water, and the provision of an air space of 500 c.c. The graduated tube should measure a total volume of 5 c.c. and afford readings in 1/20th c.c. A tube of this capacity would be about 186 mm. long and 5·5 mm. bore. The capacity of the bulb *a*1 should be 5 c.c.

For the third of the above enumerated purposes, A and B should each have a capacity of 1,500 c.c. The graduated tube should give readings in 1/20th c.c., with a total of 10 c.c. Such a tube would be about 225 mm. long and 7 mm. bore. The bulb *a*1 should have a capacity of 10 c.c.

The maximum volume of oxygen absorbed in B, which would be recordable by this last apparatus would slightly exceed 50 c.c. This would amount to half the total volume of oxygen in the air space, which should certainly be taken as the maximum allowable reduction of the oxygen in the air supply in B. Hence if the polluted water to be examined be an unpurified sewage, it would be necessary to dilute it to five or ten times its volume with tap water, or to replenish the oxygen in the atmosphere of B by the addition of fresh oxygen, which can very easily be done in the following manner :—A store of oxygen is kept in an ordinary Lunge's nitrometer over a saturated solution of common salt. After a reading of the volume of water which has risen in the graduated connecting tube of the apparatus has been taken, the nitrometer is connected by a short piece of capillary rubber tubing to *b*2, and its pressure tube is raised so as to cause a pressure upon the oxygen a little greater than that of the atmosphere. The stopcock *b*, and that of the nitrometer are next opened, and then the stopcock *b*2 is cautiously opened, and oxygen is allowed to bubble up through the water in B into its air-space until the level of the water in the graduated tube sinks to that of the zero mark on the scale. The stopcock *b*2 is then closed, and if the operation has been correctly carried out, the atmosphere in B will have been restored to its original composition, and the volume of oxygen which the nitrometer has lost will also be a measure of the oxygen which has been absorbed by the polluted water in B. In this simple way the oxygen in the atmosphere of B may be replenished from time to time, and so the rate of absorption of the most highly polluted sewage may be observed until the sewage becomes entirely self-purified under aerobic conditions.

The above dimensions have all been adopted with the view of allowing the use of volumes of polluted water sufficiently large for subsequent chemical analysis, if such be necessary. If, however, this be not necessary, as in many cases it will not be, the apparatus may be reduced to one-tenth the sizes above given. A. and B. would then have a capacity of 120 to 150 c.c. each, and the gradauted tube would read to 1/100th c.c., and have total capacity of 0·3 c.c. Such a tube would be about 50 mm. long, and 2 mm. bore. The bulb *a*1 should have a capacity of 1 or 2 c.c., according to whether it be required for the first or second of the above purposes.

The experiments which have been so far made go to show that the magnesium hydroxide, which it is necessary to add to polluted waters in order to fix free carbon dioxide in them, does not affect the rate of fermentation of the sewage matters. Neither does it appear to affect the organic matters in the sewage. It does, however, affect the ammonium compounds, as it reduces their quantity apparently by co-precipitation. This, however, does not affect the value of the method, since, if it be necessary, the true quantity of ammonia in the sewage can be determined before the addition of magnesium hydrate, and the total volume of oxygen which would be absorbed by its complete nitrification can be ascertained by calculation in the way already described. It may here be noted that calcium hydrate, even in very small quantities, cannot be substituted for magnesium hydroxide, as it exercises a retarding effect upon the subsequent fermentation of the sewage matters.

Experience with this apparatus has shown it to be capable of yielding accurate and extremely important results with a minimum expenditure of time and labour.

W. E. Adeney,

Royal University, Dublin.

APPENDIX.

REPLIES TO A CIRCULAR LETTER SENT TO MEDICAL OFFICERS OF HEALTH OF TIDAL LOCALITIES WITH REFERENCE TO THE SEWAGE AND SEWAGE DISPOSAL OF THEIR DISTRICTS.

APPENDIX TO REPORT ON THE POLLUTION OF ESTUARIES AND TIDAL WATERS.

REPLIES TO CIRCULAR LETTER.

ABERDEEN (CITY).

QUESTION.	ANSWER
1. Population of drainage area?	153,497 in 1901. Now about 164,000
2. Approximate volume of sewage discharged per diem?	7,000,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary domestic, and no special trade wastes.
A typical analysis should be given, if possible.	The following analyses have been made for the purposes of this Return. The samples were so taken as to represent the sewage of the different districts of the city, the weather being at the time dry:—

—	No. I.	No II.	No. III.	No. IV.
	Grains per Gallon.			
Suspended and Dissolved Solids	73·5	57·4	74·6	59·0
Loss on Ignition	27·3	28 8	38·1	27·5
Dissolved Solids	36·7	38·9	28·2	27·9
Loss on Ignition	10·3	11·4	10·4	11·0

QUESTION.	ANSWER
	(The samples were collected between 11.30 a.m. and 12.30 p.m.)
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	— —
A typical analysis of the treated sewage should be given, if possible.	
6. Is the sewage or treated effluent discharged at all states of the tide?	Practically the whole of the sewage is discharged at all states of the tide, but automatic tidal valves are provided on several of the outfalls.
7. If not, during what period and at what state of the tide does the discharge take place?	—
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The tides are rapid near the outfalls. The flood tide carries the sewage out to sea and then in a southerly direction past Girdleness Point; the ebb tide flows towards the north-east of Aberdeen Bay.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	At present there are four different outfalls into the tidal waters of the River Dee, three into the tidal waters of the River Don, and three into the Don about half a mile above the highest limit of the tidal waters. The depth of water at the outfalls into tidal waters varies, but, generally, the discharge takes place at about ordnance datum level, or nearly mean tide. The high water mark of ordinary spring tides is 7·35 feet above ordnance datum, and the low water mark is 5·40 ft. below ordnance datum. The whole of the outfalls are in course of being intercepted by a new scheme of drainage which is to carry the sewage through a tunnel in a ridge on the south of the Dee, and then along the north side of the Bay of Nigg to an outfall at Girdleness Point. This outfall is 21 ft. below high water mark O.S.T., or about 8 ft. below low water mark. The flood tide will carry the sewage rapidly into deep water in a southerly direction and away from the shore, while the ebb tide will carry it in a north easterly direction, also away from the shore. Two small low level areas, amounting to 3 2 acres will still continue to discharge into the tidal waters of the Dee, the level of the discharging points being 10½ and 13 ft. below high water mark O.S.T., respectively.

ABERDEEN (CITY)—*continued.*

QUESTION.	ANSWER.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	There has been no obvious nuisance hitherto. The chief reason for the new scheme has been the rapid growth of the city and the insufficiency of existing outfalls and the liability to flooding in the low-lying areas.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	No. I have consulted Professor Trail, F.R.S., of the Botanical Department of the University, and he is satisfied there is no unusual growth of such sea weeds. No nuisance arises from decomposing sea weeds.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	The harbour officials state that a deposit of sewage sludge occurs in the estuary of the Dee at Point Law, near the dock gates, but they have never complained of it, and it has not been the occasion of any obvious nuisance. It will now disappear under the new sewage scheme.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	Complaints have occasionally been made by those interested in the salmon fishings in the estuary of the Dee, as to possible harm to the fish, but no actual harm has ever been proved.
14. Please furnish any further information of a similar nature which you may think useful.	
	I have to express my indebtedness to Mr. G. Clonway, engineer in charge of the new sewerage works, for the greater part of the information contained in the above replies.

MATTHEW HAY, M.D.,

Medica' Officer of Health.

8th April, 1904.

BANGOR.

QUESTION.	ANSWER.
1. Population of drainage area?	11,275.
2. Approximate volume of sewage discharged per diem?	450,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary house sewage. No trade effluent.
A typical analysis should be given, if possible.	Report of Analyst, Dr. F. N. MENZIES, King's College, London. Slight fœcal odour. Saline and free ammonia - - - - - 0·9 parts per 100,000 Albuminoid ammonia - - - - - - 1·8 ,, Oxygen absorbed in 2 hours at 80° F. - - 1·58 ,, ,, Chlorine - - - - - - - - 6 ,, ,, Nitrogen as Nitrates and Nitrites - - - Traces Total solids - - - - - - Not estimated. Bacteriology— (*a*) No. of organisms - - - - - - 1,700,000 per c.c. (*b*) Enteritidis sporogenes - - - - - 50 ,, ,, in 48 hours (*c*) Coli - - - - - - - 20,000 per c.c. in 48 hrs. (?) 50,000 in 5 days. Typhoid and Cholera not examined for. (signed) F. N. MENZIES.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	—
A typical analysis of the treated sewage should be given, if possible.	—
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes
7. If not, during what period and at what state of the tide does the discharge take place?	—
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Varies according to the state of the tide (from sluggish to rapid, from 0 to 4 knots an hour). Flowing tide flows through Menai Straits towards N.E. ebbing tide flows through Straits to S.W.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	One 600 yards; second 430 yards
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	At the second one some years ago complaints were received of sewage being emitted from ventilators as tide was making. These ventilators have now been closed, and no nuisance is occasioned.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.

BANGOR—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No. There are extensive mud deposits in the Straits near Bangor due to the deposition of solids washed from the shore and brought down by the streams. These mud deposits show some evidence of sewage. P. FRASER.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No. No complaints as regards fish proper, but oyster layings on the shore have had to be removed on account of sewage. P. F.
14. Please furnish any further information of a similar nature which you may think useful.	

JOHN GILL, A.M.Inst., C.E.,

City Surveyor.

Bangor, 11th March, 1904.

BARMOUTH.

QUESTION.	ANSWER.
1. Population of drainage area?	2,800.
2. Approximate volume of sewage discharged per diem?	Cannot say.
3. Nature of sewage and trade effluents (if any)?	House sewage with surface water. No trade effluents.
A typical analysis should be given, if possible.	----
4. Is the sewage discharged in the crude state?	Yes
5. If not, to what process of treatment is it first subjected?	----
A typical analysis of the treated sewage should be given, if possible.	----
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	At ebb tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Two outlets, one in mouth of River Mawddach, the other in the Bay. The former is very rapid, the latter fairly so.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Each outfall a quarter of a mile. (*a*) 5 to 6 feet, (*b*) 18 to 20 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	A great abundance of green sea weeds grow in the estuary, and on a hot summer's day the smell of decomposing sea weed is very strong; this is always put down to sewage by visitors, and is therefore a nuisance.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids.	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No, none. I believe the fish are benefited by the discharge.
14 Please furnish any further information of a similar nature which you may think useful.	Our system here appears to work well. The drain water gets into the sewage pipes and thereby causes much inconvenience, but from the Commission's point of view it would not be disadvantageous. D. ARTHUR HUGHES.

BARROW-IN-FURNESS.

QUESTION.	ANSWER.
1. Population of drainage area ?	65,010 Barrow. 10,000 Dalton. 75,010
2. Approximate volume of sewage discharged per diem ?	4,000,000 gallons per day in dry weather. In wet weather this amount is considerably increased, and the sewage diluted by storm water.
3. Nature of sewage and trade effluents (if any) ?	Chiefly ordinary domestic sewage, free from any trade effluents.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state ?	Yes ; with the exception of that from Vickerstown North and South, amounting to about 100,000 gallons per day, which is passed through septic tanks before being discharged into Walney Channel.
5. If not, to what process of treatment is it first subjected ?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide ?	We have 17 outfall sewers at different points within the borough, ranging in size from 4 feet diameter to 9 inches in diameter. Of these the largest, the main outfall sewer, is tide-locked during the period from two hours before and two hours after high water.
7. If not, during what period and at what state of the tide does the discharge take place ?	See above.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Moderately rapid.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	The main outfall is situated at about 1,200 yards from the shore, and is 19 feet below high-water mark of spring tides and 9 feet above low-water mark of spring tides. The others, and less important outfalls, are situated at various distances from the shore and at various heights above or below low-water mark, as the case may be.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	Not that I am aware of.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	No
14 Please furnish any other information of a similar nature which you may think useful.	——

JOHN SETTLE.

BELFAST.

Question.	Answer.
1. Population of drainage area?	Census 1901, 349,180.
2. Approximate volume of sewage discharged per diem?	We have no exact determination thereof, but it would be about 11,000,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic sewage and surface water. The trade effluents consist of refuse from distilleries, breweries, and bleach and dye works with occasionally considerable quantities of tar product.
A typical analysis should be given, if possible.	TYPICAL ANALYSES OF BELFAST SEWAGE AND EFFLUENT.

QUANTITIES IN PARTS PER 100,000.

—	Solids in Suspension.			Chlorine.	Oxygen Absorbed. Test at 80° F.	Nitrogen as			
	Volatile.	Fixed.	Total.			Free Ammonia.	Alb. Ammonia.	Nitrite.	Nitrate.
CRUDE SEWAGE	21·40	9·00	30·40	47·8	11·01	1·98	1·48	0	0·165
Effluent (after double contact)	Traces	Traces	Traces	36·9	1·47	0·20	0·20	0	0·453

Question.	Answer.
4. Is the sewage discharged in the crude state?	Yes, except about one-seventh part of the whole, which is treated in double contact Bacteria beds.
5. If not, to what process of treatment is it first subjected?	See under 4.
A typical analysis of the treated sewage should be given, if possible.	See under 3.
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	It is discharged only during periods of 3½ hours, commencing at each time of high water; during wet weather, however, this rule is broken. The effluent from the Bacteria beds is discharged during the period of low water.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Sluggish in the direction of the sewage flow.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Distance of outlet from nearest high water mark is one mile. Depth of water at low tide (spring) 5 feet, at high (spring) tide, 14 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Yes, due to the presence of green sea-weed.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	There is a very large growth of *ulva latissima* along the shores of Belfast Lough, but none near the outfall. *Enteromorpha* (*compressa*) and *intestinalis* also occur in smaller quantities; the decomposition of these gives rise to a nuisance.

BELFAST—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	Yes, in the immediate neighbourhood of the outfall, but not to any great extent.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	None.
14. Please furnish any further information of a similar nature which you may think useful.	———

HENRY WHITAKER, M D.

BERWICK.

Question.	Answer.
1. Population of drainage area?	6,900 acres.
2. Approximate volume of sewage discharged per diem?	400,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic.
A typical analysis should be given, if possible.	None taken.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid and east direction.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Less than 200 yards. (*a*) 1 foot; (*b*) 17 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Yes, one time when valve of drain was out of repair.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	None; principally shingle.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Very little, if any.
13. Have any complaints been made as regards the effects of the discharge on fish life?	None.
14. Please furnish any further information of a similar nature which you may think useful	——

D. Heagert

COUNTY BOROUGH OF BIRKENHEAD.

QUESTION.	ANSWER.
1. Population of drainage area?	114,814.
2. Approximate volume of sewage discharged per diem?	2,870,350 gallons
3. Nature of sewage and trade effluents (if any)?	Practically all domestic sewage.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid, practically at right angles to line of outflow.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	1. At river wall. Invert 3 feet 8 inches above low-water mark of ordinary tides, and 23 feet 10 inches below high-water mark ordinary tides. 2. At river wall. Invert 3 feet 4 inches below low-water mark of ordinary tides, and 30 feet 10 inches below high-water mark ordinary tides. 3. 287 yards from shore. Invert 11 feet 7 inches above low-water mark of ordinary tides and 15 feet 11 inches below high-water mark ordinary tides. 4. 267 yards from shore. Invert 13 feet 10 inches above low-water mark of ordinary tides, and 13 feet 8 inches below high-water mark ordinary tides. 5. 262 yards from shore. Invert 3 feet 11 inches above low-water mark of ordinary tides and 23 feet 7 inches below high-water mark ordinary tides. 6. 277 yards from shore. Invert 4 feet above low-water mark of ordinary tides and 23 feet 6 inches below high-water mark ordinary tides.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Not to my knowledge.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.

COUNTY BOROUGH OF BIRKENHEAD—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No
14. Please furnish any further information of a similar nature which you may think useful?	—
	15th July, 1904. CHAS. BROWNRIDGE, Borough Engineer and Surveyor.

BLACKPOOL.

QUESTION.	ANSWER
1. Population of drainage area	Estimated population approximately 54,000.
2. Approximate volume of sewage discharged per diem?	1,575,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic sewage. No trade effluents of any importance.
A typical analysis should be given if possible.	I regret that I have no analysis available.
4. Is the sewage discharged in the crude state?	Yes.
5. If not to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No; not at main outfall. North outfall, which serves only a small portion of the town, discharges at all states of the tide. The outflow end of the outfall pipe is at low water mark.
7. If not, during what period and at what state of the tide does the discharge take place?	The valves in the penstock chamber are opened about two hours after full tide and closed about two before low tide, so that the sewage is only discharged with the ebbing tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Neither sluggish nor very rapid, but a moderately rapid tide. Incoming tide about N.W.; outgoing tide S.W.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Main outfall 800 yards from hulking; depth of water over it at low (spring) tide nil, the mouth of the pipe being almost completely exposed; at high (spring) tide covered with 29 feet of water. North outfall about 440 yards from hulking. At low (spring) tide outlet partially bare for a short time; at high (spring) tide 29 feet of water covering it.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Some years ago the outfall pipe became broken about half way between the outlet and the shore, leading to pollution of the foreshore. Since this was remedied no nuisance is found from this source, except to a slight extent, occasionally with a strong S.W. wind continuing for some days, or if through any neglect the valves in penstock chamber are left open too long.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Not to any extent; a slight deposit of sludge is occasionally observable on the edge of the outgoing tide near low water.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No; fishermen regard it as a good breeding ground. The Fisheries Board of the Lancashire County Council have made it a closed ground, and neither trawlers nor shrimpers are allowed on the Blackpool foreshore, with the intention, as I am informed, of protecting the breeding grounds.
14. Please furnish any further information of a similar nature which you may think useful.	Some evidence has been obtained that typhoid fever has been contracted through the consumption of mussels obtained from the Blackpool piers or from the sewer outfall pipes. Dr. Bulstrode, in his evidence before the Commission, quoted the opinions arrived at by my predecessor (Dr. Anderson) and myself and recorded in our annual report.

FRANCIS J. H. COUTTS,
Medical Officer of Health, Blackpool.

BOGNOR.

QUESTION.	ANSWER.
1. Population of drainage area?	About 6,500.
2. Approximate volume of sewage discharged per diem?	650,000 gallons including surface water.
3. Nature of sewage and trade effluents (if any)?	
A typical analysis should be given, if possible.	—— ——
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	No treatment.
A typical analysis of the treated sewage should be given, if possible.	—— ——
6. Is the sewage or treated effluent discharged at all states of the tide?	No, at half-ebb and low-water.
7. If not, during what period and at what state of the tide does the discharge take place?	As above.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid; flows east and west. The discharge or outfall pipe empties at the mouth of the river, which greatly assists in carrying the sewage towards the open sea.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Near low water mark, 500 feet from the shore; at low water (spring) tides the pipe is exposed. At high water there would be about ten feet of water over.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore	Not to my knowledge.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	—— ——

W. CONWAY COOKE,
Medical Officer of Health.

COUNTY BOROUGH OF BOURNEMOUTH.

<table>
<tr><th>Question.</th><th>Answer.</th></tr>
<tr><td>1. Population of drainage area ?</td><td>52,000.</td></tr>
<tr><td>2. Approximate volume of sewage discharged per diem ?</td><td>The system is in most part a combined one. The amount of sewage has not been actually ascertained, but is estimated at 1,300,000 gallons per diem.</td></tr>
<tr><td>3. Nature of sewage and trade effluents (if any) ?</td><td>There are no trade effluents dealt with.</td></tr>
<tr><td>A typical analysis should be given, if possible.</td><td>——</td></tr>
<tr><td>4. Is the sewage discharged in the crude state ?</td><td>Yes.</td></tr>
<tr><td>5. If not, to what process of treatment is it first subjected ?</td><td>——</td></tr>
<tr><td>A typical analysis of the treated sewage should be given, if possible ?</td><td>——</td></tr>
<tr><td>6. Is the sewage or treated effluent discharged at all states of the tide ?</td><td>At all states of the tide.</td></tr>
<tr><td>7. If not, during what period and at what state of the tide does the discharge take place ?</td><td>——</td></tr>
<tr><td>8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?</td><td>Tides set sharply past the outfall and out of the bay, either towards the Isle of Wight or Isle of Purbeck as the tide flows or ebbs.</td></tr>
<tr><td>9. At what distance from the shore is the outfall situated, and in what depth of water (<i>a</i>) at low (spring) tide and (<i>b</i>) at high (spring) tide ?</td><td>
<table>
<tr><th>Outfalls.</th><th>Distance from shore.</th><th>Depth below mean tide level.</th></tr>
<tr><td>18 in. and 36 in.</td><td>1,300 ft.</td><td>24 ft.</td></tr>
<tr><td>Bournemouth Pier.
18 in. and 36 in.</td><td>2,016 ft.</td><td>36 ft.</td></tr>
<tr><td>Boscombe Pier.
24 in.</td><td>1,370 ft.</td><td>24 ft.</td></tr>
<tr><td>Southbourne.
21 in.</td><td>1,400 ft.</td><td>33 ft.</td></tr>
</table>
The range of tides is 6 ft.
In addition to the above there are storm water outfalls as follows :—48 in. at Bournemouth Pier, 1,320 ft. long, discharging in 22 ft. water ; 36 in. at Boscombe Pier, 1,100 ft. long, discharging into 18 ft. of water.</td></tr>
<tr><td>10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?</td><td>No ; all trace is carried away by set of tide.</td></tr>
<tr><td>11. Is there any considerable growth of green sea weeds (such as <i>ulva latissima</i> or the different varieties of <i>enteromorpha</i>) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?</td><td>The bay both generally and near the outfalls is quite clear of growth.</td></tr>
</table>

COUNTY BOROUGH OF BOURNEMOUTH—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful?	———

PHILIP W. G. NUNN,
Medical Officer of Health.

BRIDGEND URBAN DISTRICT AND PART OF PENYBONT RURAL DISTRICT.

QUESTION.	ANSWER.
1. Population of drainage area ?	Contributory places, estimated 1904=6523. Bridgend Urban District „ 1904=6614. Total population „ 1904=13,137.
2. Approximate volume of sewage discharged per diem ?	Estimated at 90 cubic feet per minute=129,600 cubit feet in 24 hours.
3. Nature of sewage and trade effluents (if any) ?	Tanyard, Brewery, Laundry, Aerated Water Co. ; ordinary sewage and slop water from dwelling houses with the surface water of back yards in wet weather.
A typical analysis should be given, if possible.	No analysis has been made.
4. Is the sewage discharged in the crude state ?	Yes.
5. If not, to what process of treatment is it first subjected ?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide ?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place ?	The sewage is tidal locked for about two hours at each tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Rapid ; four or five miles an hour ; east and west.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	1,400 yards from low water mark. (*a*) 15 feet 6 inches. (*b*) 44 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	No.
14. Please furnish any further information of a similar nature which you may think useful	The sewage works have been completed only eighteen months ago, 1902-1903 so there is hardly time for nuisance to betray itself yet. WYNDHAM RANDALL, 7th July, 1904. Bridgend.

BRIGHTLINGSEA.

QUESTION.	ANSWER.
1. Population of drainage area ?	The estimated population of the entire district at the middle of 1903 was 4,640. Population at August, 1901, 4501. From this should be deducted 150, the approximate number not draining into the sewerage system.
2. Approximate volume of sewage dischaged per diem ?	50,000 gallons.
3. Nature of sewage and trade effluents (if any) ?	There are no trade effluents.
A typical analysis should be given, if possible.	The following results were obtained from a sample of the sewage taken on a surprise visit to the works :— 1. Colour in 6th column, dirty brown, very turbid and opaque. 2. Odour very offensive. 3. Contained much free ammonia. 4. Contained 18 grains of chlorine per gallon, equivalent of sodium chloride 30 grains. (The public supply water contains 10 grains of chlorine per gallon.) 5. 3·75 grains of oxygen absorbed in four hours at 80° Fahrenheit. 6. On being allowed to stand for ten days emitted sulphuretted hydrogen.
4. Is the sewage discharged in the crude state ?	No.
5. If not, to what process of treatment is it first subjected ?	Alumino ferric precipitation process (Ive's patent).
A typical analysis of the treated sewage should be given, if possible.	The following results were obtained from a sample of the effluent corresponding to the sewage mentioned in section 3 :— 1. Colour in 6th column very faint grey blue; no turbidity and quite transparent. 2. Faint odour but not unpleasant. 3. Contained trace of ammonia. 4. Contained 14 grains of chlorine per gallon, equivalent in sodium chloride 23·3 grains per gallon. (Public supply water contains 10 grains of chlorine per gallon.) 5. 0·7 grain of oxygen per gallon absorbed in four hours at 80° Fahrenheit. 6. On standing for ten days did not become offensive nor emit sulphuretted hydrogen.
6. Is the sewage or treated effluent discharged at all states of the tide ?	No.
7. If not, during what period and at what state of the tide does the discharge take place ?	Between one hour after high water and one hour before low water.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Rapid. Their direction is shown on the accompanying maps. A series of floats were placed in the water and their direction noted as shown on the map. High water was at 12 noon. No. 1 float was put in at 1 o'clock „ 2 „ „ „ „ 1.20 „ „ 3 „ „ „ „ 1.50 „ „ 4 „ „ „ „ 2.40 „ „ 5 „ „ „ „ 3 „ „ 6 „ „ „ „ 3.15 „ , 7 „ „ „ „ 3.45 „ „ 8 „ „ „ „ 4.15 „
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	From high mark (ordinary tides) the distance is 110 feet. This mark corresponds with the shore of the salt marsh. (*See* Map.) (*a*) nil, (*b*) 12 feet. As the shore is a gentle slope a very small rise in the tide covers the outlet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	No.

Brightlingsea—*continued.*

Question.	Answer.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further informaton of a similar nature which you may think useful.	No oysters nor other shellfish are cultivated in Brightlingsea Creek for a distance of 250* from the sewage outfall ; the District Council renting the oyster layings for that distance. The sludge from the sewage works is all used on the land as manure, none being deposited in the sea. E. P. DICKIN.

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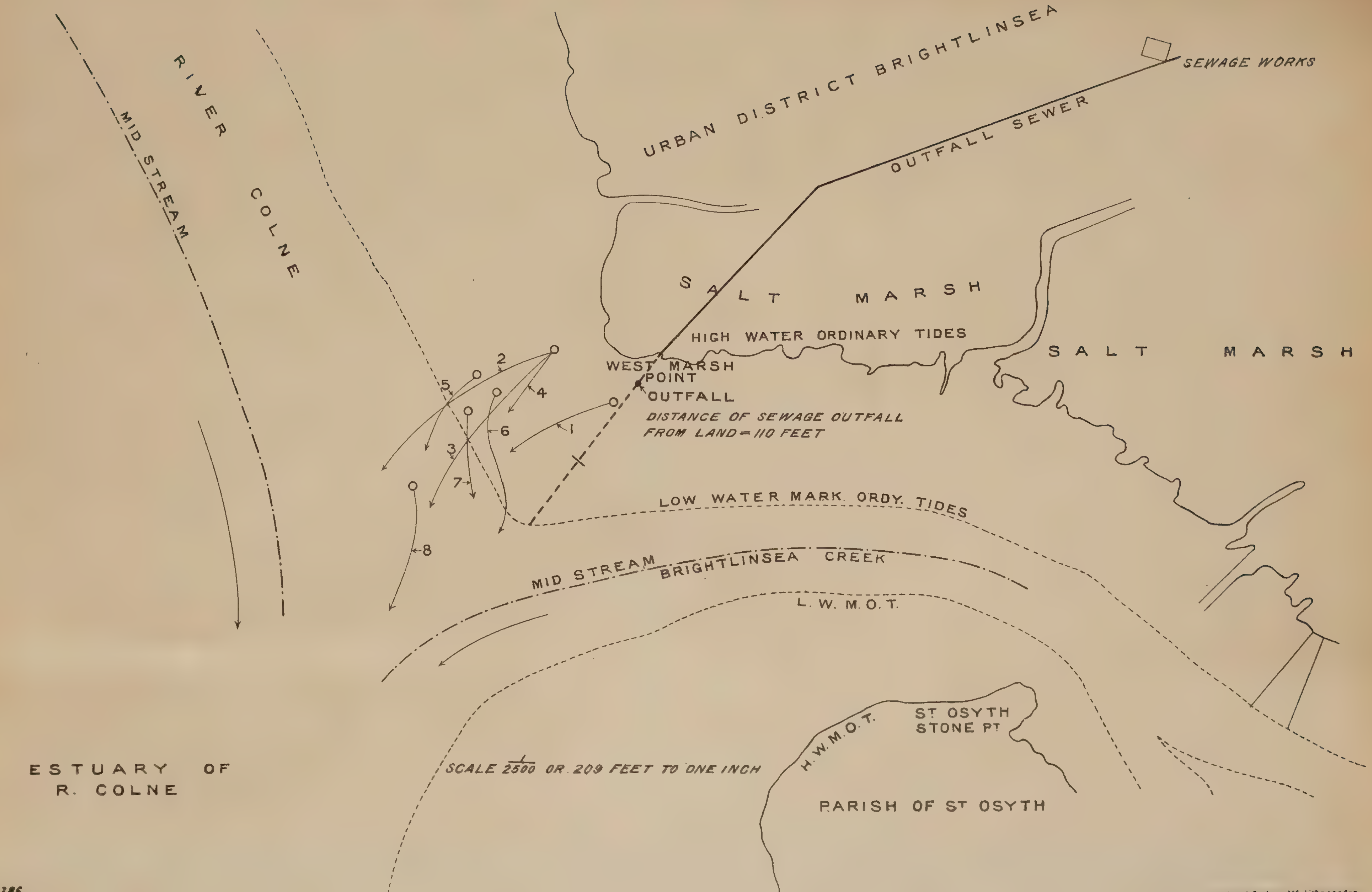
* This is the distance laid down but is actually exceeded.



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BRIGHTON.

QUESTION.	ANSWER.
1. Population of drainage area?	155,165.
2. Approximate volume of sewage discharged per diem?	7,137,590 gallons per 24 hours.
3. Nature of sewage and trade effluents (if any)?	There are no trade effluents.
A typical analysis should be given, if possible.	No analyses have been made, but the sewage is probably very dilute.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	No. The sewer being tide-locked, only discharges at low water.
7. If not, during what period and at what state of the tide does the discharge take place?	Discharge takes place between half-tides.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rate 1½ to 2½ knots. Direction is westerly at fall of tide, and easterly at rise of tide.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	1,028 feet 6 inches from face of cliff; at a distance of 5,867 yards, or 3⅓ miles from the eastern boundary of the borough, and far remote from any inhabited district, except a few houses at Telscombe. Depth of water—(*a*) Low spring tide, 3¼ feet. (*b*) High „ „ 23 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	None whatever.
14. Please furnish any further information of a similar nature which you may think useful.	——

A NEWSHOLME.

BRISTOL.

QUESTION.	ANSWER.
1. Population of drainage area?	341,000.
2. Approximate volume of sewage discharged per diem?	8,500,000 gallons
3. Nature of sewage and trade effluents (if any)?	Varies considerably at each outfall, and again at different periods during the day.
A typical analysis should be given, if possible	The sewage discharged from six of the seven outfalls is domestic in type, and varies only in degree of concentration. The average composition calculated from separate analyses of samples collected at these outfalls is given below, together with a typical analysis of that from the seventh outfall, at which much trade waste is discharged, and the character and reaction of the sewage vary a good deal.

——	Average of Six Sewages.	Single Sewage.
	Grains per Gallon.	
Saline ammonia - - - - -	5·05	3·57
Albuminoid ammonia - - - -	·832	·486
Chlorine as chloride - - - -	21·7	55·2
Oxygen absorbed in 15 min. - - -	1·516	1·092
,, ,, 4 hrs. - - -	4·076	2.405
Dissolved organic solids - - - -	32·90	51·0
,, mineral ,, - - - -	78·40	101·0
Suspended organic ,, - . - -	17·80	32·2
,, mineral ,, - - - -	11·40	113·93

QUESTION.	ANSWER.
4. Is the sewage discharged in the crude state?	Yes; except two small districts now remote from the main sewerage system, but which are at present being connected up.
5. If not, to what process of treatment is it first subjected?	The sewage from the two districts named in No. 4 is treated by means of a septic tank and continuous filtration.
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	The outfalls are fitted with tidal flaps. A discharge can only take place when the head in the sewer is greater than the level of the tide.
7. If not, during what period and at what state of the tide does the discharge take place?	Usually at low water (*see* answer to No. 6).
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid; generally nearly at right angles to the line of sewers.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide.	The outfalls are into the river Avon. The depth of water at low tide depends upon the quantity of fresh water in the river; the depth of water against the outfalls at high spring tide is about 18 feet. The difference in level between high water and low-water at ordinary spring tides is 41 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Only during a very dry season.

BRISTOL—*continued.*

QUESTION.	ANSWER.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No fishing takes place in that part of the river where the outfalls are situate.
14. Please furnish any further information of a similar nature which you may think useful.	The above particulars have been filled in with the kind assistance of the City Engineer (Mr. T. H. Yabbicom, M.Inst.C.E.) and of the City Analyst (Mr. F. W. Stoddart, F.I.C., F.C.S.).

D. S. DAVIES, M.D.,
Medical Officer of Health.

CARDIFF.

QUESTION.	ANSWER.
1. Population of drainage area?	176,313 (Urban Sanitary District, Cardiff), estimated population middle of 1904.
2. Approximate volume of sewage discharged per diem?	At the rate of 20 gallons per head of the population (dry weather flow).
3. Nature of sewage and trade effluents (if any)?	Ordinary domestic sewage from water closets. Trade effluents insignificant in amount.
A typical analysis should be given, if possible.	RESULTS OF ANALYSES OF CRUDE SEWAGE.

RESULTS OF ANALYSES OF CRUDE SEWAGE.

CARDIFF AND COUNTY PUBLIC HEALTH LABORATORY,

9, The Parade, Cardiff.

Report on Analysis of Sample of Sewage. Received on March 11th, from Dr. Walford. Labelled Main Sewer Outfall. West side of Taff. Under water at high tide.

No. of Sample			316.
Date of Analysis			March 12th–19th.
Appearance in two-foot tube			Very turbid. Considerable amount of suspended matter.
Reaction			Alkaline.
Total Solid Matter		In parts per hundred thousand.	86·3, containing org. m. 27·2
(a.) In Solution			70·2 ,, ,, 18·1
(b.) In Suspension			16·1 ,, ,, 9·1
Appearance on Ignition			Considerable blackening.
Chlorine			10·8.
Nitrates and Nitrites			Nil.
Oxygen absorbed from Permanganate (in 4 hours at 80° F.)			3·51.
Saline (or "Free") Ammonia			2·53.
Organic (or "Albuminoid") Ammonia			·53.
Keeping Properties			
Incubator Test	7 days		Distinctly putrescible.
Oxygen absorbed in 3 mins.			Increase in readily oxidizable matter 1·98
Before	1·34		
After	3·32		

Chemical analysis shows the sample to be a sewage of a moderately strong character, containing nitrogenous organic matter in fairly large amount, and a considerable amount of suspended matter. It is distinctly putrefactive.

21st March, 1904. J. H. SUGDEN.

Report on Analysis of Sample of Sewage, received on March 11th, from Dr. Walford. Labelled Sewer Outfall. East side of Taff. Under water at high tide.

No. of Sample			317.
Date of Analysis			March 12th–19th.
Appearance in two-foot tube			Very turbid. Large amount of suspended matter.
Reaction			Alkaline.
Total Solid Matter		In parts per hundred thousand.	423·7, containing org. m. 71·4
(a). In Solution			395·5 ,, ,, 48·9
(b). In Suspension			28·2 ,, ,, 22·5
Appearance on ignition			Large blackening.
Chlorine			180·0.
Nitrates and Nitrites			Very faint traces.
Oxygen absorbed from Permanganate (in 4 hours at 808 F.)			5·51.
Saline (or "Free") Ammonia			4·39.
Organic (or "Albuminoid") Ammonia			1·13.
Keeping Properties			Strongly putrescible.
Incubator Test	7 days		Increase in oxygen absorbed by readily oxidizable matter 3·86.
Oxygen in 3 minutes (absorbed):			
Before	1·50		
After	5·36		

The large amounts of chlorine and of solids in solution indicate a considerable admixture with sea water.

The results of the analysis show that this sample is a stronger sewage than No. 316; the putrescibility, albuminoid ammonia, oxygen absorbed, and also the suspended matter all being greater.

March 21st, 1904. J. H. SUGDEN.

CARDIFF—*continued.*

QUESTION.	ANSWER.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place	———
8 Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid. Ebb tide in westerly direction. Flood tide in easterly direction Height of tide between 30 and 40 feet.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Close to the shore, exposed from about half ebb to half flood tide during spring tides; and entirely exposed at neap tides at high as well as at low water.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	In summer there is occasional nuisance by deposit of sewage on river bank, brought up River Taff on flood tide. Evidence of deposit at some places on foreshore. No nuisance detected, no inhabited house near.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids.	Nothing beyond small deposits mentioned in No. 10.
13. Have any complaints been made as regards the effects of the discharge on fish life.	No.
14. Please furnish any further information of a similar nature which you may think useful.	Sewerage extension scheme now being carried out, by which western sewer outfall will be carried below low water line on the foreshore, about eight miles to the west of the situation of the present outfall in the mouth of the River Taff. EDWARD WALFORD, M.D., D.P.H., Medical Officer of Health.

CARMARTHEN.

Question.	Answer.
1. Population of drainage area? -	About 8,500.
2. Approximate volume of sewage discharged per diem?	250,000 gallons.
3. Nature of sewage and trade effluents (if any)?	The sewage is of the nature usual in a town where the water-carriage system prevails and there are practically no trades.
A typical analysis should be given, if possible.	No analysis available.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Fairly rapid—to and fro.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outfall is into a tidal river, eight miles from the sea. The outfall is a few feet above the water level at low tide and is submerged for a short time at high spring tides.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Not to my knowledge.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	A suggestion was once made that the use of disinfectants might possibly prove injurious to the fish, but there was no evidence of this being the case.
14. Please furnish any further information of a similar nature which you may think useful.	—— LL. BOWEN JONES.

CARNARVON.

QUESTION.	ANSWER.
1. Population of drainage area?	About 9,500.
2. Approximate volume of sewage discharged per diem?	About 350,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary domestic sewage.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state?	Yes.
5. If not to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes; excepting when outfalls are tide-locked.
7. If not, during what period and what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	2½ knots at neap tides, 3¾ knots at spring tides, In a north-easterly and south-westerly direction through the Menai Straits.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	About 100 feet distant from shore. (*a*) About 2 feet. (*b*) About 16 feet
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Not much.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Not from sewage solids, but there are extensive mud deposits at the mouth of the river Seiont, and along the shore. This mud is to some extent impregnated with sewage.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——

P. FRASER, M.D.,
Medical Officer of Health.

Carnarvon.

CHATHAM.

QUESTION.	ANSWER.
1. Population of drainage area?	About 40,000.
2. Approximate volume of sewage discharged per diem?	No data.
3. Nature of sewage and trade effluents (if any)?	----
A typical analysis should be given, if possible.	There is at present no system of drainage in Chatham. Excrement and waste water stored in cesspools, contents of which are emptied on to land.
4. Is the sewage discharged in the crude state?	Some sewage is discharged into the Medway in its crude state, notably from Government establishments.
5. If not, to what process of treatment is it first subjected?	----
A typical analysis of the treated sewage should be given, if possible.	----
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	----
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	----
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	----
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Nuisances exist from the pollution of the foreshore at many points but there are no sewage outfall works.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	----
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	----
13. Have any complaints been made as regards the effects of the discharge on fish life?	----
14. Please furnish any further information of a similar nature which you may think useful?	No further information available. J. HOLROYDE.

CHICHESTER.

QUESTION.	ANSWER.
1. Population of drainage area?	About 13,500, as it includes the asylum and barracks.
2. Approximate volume of sewage discharged per diem?	All depends on the rainfall and subsoil water—dry, and when subsoil water under sewer, about 600,000 gallons; but when subsoil water high, quite 3,000,000 gallons.
3. Nature of sewage and trade effluents (if any)?	One tannery and one brewery with the house sewage.
A typical analysis should be given, if possible.	It varies so very much. I went to the manager of the sewage works and asked him for report of an analysis, but he has not any. Lord Gifford has brought an action against the Corporation for impure effluent, but the chemical analysis of the town and Lord Gifford's chemist differ very much in their reports.
4. Is the sewage discharged in the crude state?	No.
5. If not, to what process of treatment is it first subjected?	It is first treated with lime and chemicals, then precipitation, then filtration from a sprinkler. The chemical used the last year :— 211$\frac{9}{10}$ yards of white lime. 1,724 bags of grey lime. 37 tons 17½ cwt. of alumino ferric. 50 tons 8 cwt. of sulphalumni.
A typical analysis of the treated sewage should be given, if possible.	I have tried to get a copy of the analysis, but, as before, the experts disagree very much (Lord Gifford *v.* The Town Council). Dr. Foulerton has also made a report, and taken samples of the harbour water in six different places.
6. Is the sewage or treated effluent discharged at all states of the tide?	It is discharged after the tide has turned, but sometimes when there is very much the effluent tank is not empty at low water.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Not any tide. It is only the rise and fall of the tide.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide.	About 10 yards. At low tide the outfall pipe is always quite uncovered. At very high tide about five or six feet of water over it.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Lord Gifford's evidence stated there was I have not noticed any myself
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Very little sea weed of any kind near the outfall pipe. I cannot find or see any of these sea weeds nor can I find that anyone has seen them. After the effluent leaves the pipe, it then runs down a stoney channel. There is a small, hard, dark sea weed grows in this part.

CHICHESTER—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	I believe not.
13. Have any complaints been made as regards the effects of the discharge on fish life?	There are very few shellfish, and not so many until you get half a mile down the main channel. I have never seen a dead fish myself.
14. Please furnish any further information of a similar nature which you may think useful.	Lord Gifford is the only person to my knowledge having made a complaint, and the case is still on, and there is another hearing next November before Justice Channell at the Law Courts.
	R. HUMPHRY, Medical Officer of Health. Chichester.

CHRISTCHURCH.

QUESTION.	ANSWER.
1. Population of drainage area?	4,024.
2. Approximate volume of sewage discharged per diem?	Part only of district is sewered, discharging into rivers at various places, also into streams and watercourses, &c. It is somewhat difficult to give even an approximate calculation of volume of sewage discharged. NOTE.—A new scheme for dealing with the whole borough and treating sewage with open septic tank and bacterial filters has just received the approval of the Local Government Board.
3 Nature of sewage and trade effluents (if any)?	The nature of the sewage is purely domestic, there being no trade effluent.
A typical analysis should be given, if possible.	
4. Is the sewage discharged in the crude state?	In crude state.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid in rivers, sluggish in streams and watercourses &c.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Outfalls in river about three feet from river banks. At low spring tides about one foot below, and high spring tides about five feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Not from outfalls in rivers, but in streams and watercourses they are a constant source of nuisance.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	——
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Sludge in small quantities is deposited at times around outfalls in rivers, which are periodically cleaned. Watercourses and streams are also cleaned several times yearly.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	—— R. LLOYD LEGATE.

COLCHESTER.

Question.	Answer.
1. Population of drainage area ?	40,000 about.
2. Approximate volume of sewage discharged per diem ?	950,000 to 1,000,000 gallons.
3. Nature of sewage and trade effluents (if any) ?	Mostly domestic sewage, but also receives the brewery waste from three breweries, also one tannery.
A typical analysis should be given, if possible.	No analysis at present available.
4. Is the sewage discharged in the crude state ?	No.
5. If not, to what process of treatment is it first subjected ?	Precipitation and purification by bacteria beds. The sewage passes first into a number of settling tanks, with a combined capacity of 1,436,000 gallons. From these sedimentation tanks the sewage is subsequently run into filter beds These are six in number, with an area of 1,200 cubic yards, and consist of breeze and clinker to about a depth of 4 feet. From these beds the purified effluent passes into the river. The sludge from the sedimentation tanks flows by gravity to tanks where it is mixed with lime and pressed into cake in sludge presses. This sludge cake is sold to farmers at nominal prices.
A typical analysis of the treated sewage should be given, if possible.	No analysis of effluent at present available, but specimens kept in stoppered bottles in warm place remain quite inoffensive for at least six weeks (maximum period of testing).
6. Is the sewage or treated effluent discharged at all states of the tide ?	No.
7. If not, during what period and at what state of the tide does the discharge take place ?	Discharged on the ebb tide, as far as possible midway between ebb and flood.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Tides about three miles per hour. Tides from S.E. to N.W.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	On the foreshore of the river. Invert of discharge pipe is 4½ to 5 feet above the bed of the river.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	Not since 1884.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	Nil.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No evidence.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	Nil.
14. Please furnish any further information of a similar nature which you may think useful.	— William G. Savage.

CONWAY.

QUESTION.	ANSWER.
1. Population of drainage area? -	4,000.
2. Approximate volume of sewage discharged per diem?	140,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Weak domestic sewage.
A typical analysis should be given if possible	ANALYSIS. Examined, 29th January, 1904. Fœcal odour well marked. Parts. Free and saline ammonia - - - - - - 0·300 per 100,000 Organic ammonia - - - - 0·140 „ 100,000 Chlorine - - - - - - - 7 „ 100,000 Nitrogen as nitrates and nitrites. - Practically inestimable, the amount being very small. Oxygen absorbed in two hours at 80° F. - - - 1·25 per 100,000 Solid residue - - - - - - - 40 parts „ 100,000 There was marked charring of the residue. (Signed) F. N. MENZIES, M.D., M.R.C.P. Edin., King's College Laboratory, London.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	—
A typical analysis of the treated sewage should be given, if possible.	—
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	—
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid, about 4½ knots per hour. Up and down the river channel alternately.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outfalls are situated at low spring tide mark, and at high tides would have over 20 feet of water over them.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Nothing serious.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.

CONWAY—*contineud.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	Once, when the Conway gasworks discharged ammoniacal liquor into a stream. This has long been discontinued.
Please furnish any further information of a similar nature which you may think useful.	

P. FRASER, M.D., B.Sc.,
Medical Officer of Health,
Carnarvon

COWES, ISLE OF WIGHT.

QUESTION.	ANSWER.
1. Population of drainage area?	9,000.
2. Approximate volume of sewage discharged per diem?	135,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic.
A typical analysis should be given, if possible.	No analysis available.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid. North and south inside the harbour, and east and west outside.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outfall opposite Sun Hill is situate 170 feet below high water mark, and is covered with a depth of 2 feet of water at low water springs and 14½ feet at high water springs. The outfall at Egypt Point is situate 250 feet below high water mark, and is covered with a depth of 10 feet of water at low water springs, and 22½ feet at high water spring tides. The outfall opposite Brunswick Road is situate 200 feet below high water mark, and is covered with 2 feet of water at low water springs and 14½ feet at high water.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No nuisance attributable to sewage.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	There is a considerable growth of green sea weeds along the coast, and a nuisance has occasionally arisen from the weeds being washed ashore. It is only during the prevalence of strong westerly winds that the sea weed accumulates on the shore, and the nuisance is abated by the same being collected and barged away. No accumulation of sea weed takes place in the immediate neighbourhood of the outfalls.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	None whatever.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	———

WILLIAM HOFFMEISTER, M.D.
Medical Officer of Health.

CROMER.

Question.	Answer
1. Population of drainage area?	3,976 resident; 8,000 (approximate) during season.
2. Approximate volume of sewage discharged per diem?	80,000 gallons during winter; 160,000 gallons during season (summer months).
3. Nature of sewage and trade effluents (if any)?	Ordinary urban sewage; no trade sewage.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	No.
5. If not, to what process of treat- is it first subjected?	Passed through septic tanks (not filtered).
A typical analysis of the treated sewage should be given, if possible	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Strong current; east and west.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	When first installed it was 630 feet from shore; is now being extended to a distance of 720 feet. (*a*) 4 feet, (*b*) 18 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Originally the outlet was just at the end of the pier, and it was found that at still low tides the effluent from the septic tanks slightly discoloured the sea at the outlet, and for this reason the outlet is now being extended seawards by a distance of 90 feet.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Yes; about the end of August there is a considerable amount of sea weed deposited on the beach when the wind is off the sea, and if left *in situ* it becomes sand-logged and very offensive. It has no connection with the outflow effluent.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	

Sydney H. Long, M.D.,
Medical Officer of Health, Cromer.

37, St. Giles' St., Norwich.
27th February, 1904.

DARTMOUTH.

Question.	Answer.
1. Population of drainage area?	About 6,500.
2. Approximate volume of sewage discharged per diem?	195,000 to 200,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary house sewage. No trade refuse except one small brewery.
A typical analysis should be given, if possible.	There has been no analysis.
4. Is the sewage discharged in the crude state	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	From three hours after high water until three hours before high water again.
8. Are the tides sluggish or rapid near the point of outfall and what is their direction?	Very rapid. About four knots per hour.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	About 45 feet. (*a*) 5 feet 6 inches low spring tide. (*b*) 18 feet 6 inches high spring tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	The outfalls are carried well into the bed of a very swiftly flowing river, and after 16 years' experience in the sanitary matters of the district, I have never seen any signs of sewage in the river or fouling of the foreshore. JOHN H. HARRIS, M.D., D.P.H., Medical Officer of Health.

DEVONPORT.

Question.	Answer.
1. Population of drainage area? -	74,335, estimated to December 1904.
2. Approximate volume of sewage discharged per diem?	NOTE.—The drainage area is served by two water companies, Devonport and Plymouth; the former company serves a population of from 68 to 69 thousand. In this area the quantity of water used is about 22 gallons per head per day for domestic purposes, besides 13 gallons for meter supplies, including Admiralty supply. As most of this water runs to waste, it would give 68,000 × 35 = 2,380,000 gallons poured daily into this tide as sewage.
3. Nature of sewage and trade effluents (if any)?	Mainly domestic. No large factories.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state?	Yes, save that about 200 houses in a rural area are drained into a septic tank (Exeter patent), which system is to be further extended to take in a large and scattered area, involving at present many hundreds of houses, and likely to be much increased. The effluent of the small tank above is clear and free from smell. This is discharged into the tide. This is the only point from which any water finds its way into the Hamoaze from the outside area, served by the Plymouth Water Company, except the overflow from one cesspit. Many houses here are drained into cesspits; so that practically there is no amount of any importance of polluted water discharged from this area seeing that the effluent from this septic tank is free from colour and smell, and the amount of crude sewage discharged is small, being derived from less than 100 houses.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	Practically pure.
6. Is the sewage or treated effluent discharged at all states of the tide?	At all states.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Tides are rapid for the most part but there is some backwater which is polluted to a great extent. The Admiralty have forbidden the discharge of any more untreated sewage into the tidal river, the Hamoaze, which emerges into the Tamar.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	There are three main outfalls, two directly discharging into water along shore.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	It has ruined a bathing place close by, discolouring the water, and causing accumulation of waste paper, &c.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Not that I am aware of; the rapid current would prevent this save in some quiet corners and backwaters to a limited extent.

DEVONPORT—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	An estuary has been gradually filled up, and being offensive has been filled in and made into a public garden for some distance, but the remainder towards the sea is ruined for purposes of navigation, save at high tides. This filling up or silting is much due to sand, which was for long a trouble, in causing choking of the drains before discharge into the estuary.
13. Have any complaints been made as regards the effects of the discharge on fish life?	Not that I know of, but there is practically no fishing in the water under consideration. When the sewage gets carried out into the Plymouth Sound, it becomes mixed with the sewage of that town, with what results to fishing I do not know.
14. Please furnish any further information of a similar nature which you may think useful.	—

J. A. MAY.

DOVER.

QUESTION.	ANSWER.
1. Population of drainage area?	44,000.
2. Approximate volume of sewage discharged per diem?	1,100,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary sewage with one brewery and three paper mills.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid ; about six to seven knots per hour, in a westerly direction.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	1,220 feet. (*a*) 26 feet (*b*) 45 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Not since the outfall was extended many years ago.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Sea weed does exist between the outfall and the shore. Weeds have been washed ashore, but not to any serious extent, in recent years.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Not recently.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No. Fish congregate and are caught near the outfall.
14. Please furnish any further information of a similar nature which you may think useful.	With certain winds, the Medical Officer of Health has noticed the floating sewage blown towards the shore, and he does not bathe under such conditions. The inhabitants and visitors do not appear to notice the same.

M. K. ROBINSON, M.D.
Medical Officer of Health.

DUBLIN.

QUESTION.	ANSWER.
1. Population of drainage area ?	Estimated population 324,000 (for present drainage scheme), and which may yet be increased by 58,126 under the terms of the Extension of the Boundaries Act, 1900.
2. Approximate volume of sewage discharged per diem ?	5,010 cubic feet per minute wet weather flow for 324,000.
3. Nature of sewage and trade effluents (if any) ?	Except breweries and distilleries, there are no manufactories in Dublin of any importance.
A typical analysis should be given, if possible.	—
4. Is the sewage discharged in the crude state ?	At present it is discharged into the river, along the quays, north and south, in its crude state.
5. If not, to what process of treatment is it first subjected ?	Works in connection with lime precipitation are in course of construction at Pigeon House, and will be completed in about fifteen months (from March, 1904).
A typical analysis of the treated sewage should be given, if possible.	—
6. Is the sewage or treated effluent discharged at all states of the tide ?	It will be.
7. If not, during what period and at what state of the tide does the discharge take place ?	—
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	—
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	The outfall for the new outfall works, which is not yet working, is 35 ft. from shore ; (*a*) outlet just covered at low water of spring tide ; (*b*) top of outlet is 13 ft. under high water of spring tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	—
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	*Ulva latissima* is noticed at the point of outfall at present, though there is no sewage discharge from it.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	A bank seems to have accumulated at the west of the Outfall Works, probably from a storm outlet of the Rathmines and Pembroke Main Outfall Sewer.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	—
14. Please furnish any further information of a similar nature which you may think useful.	—

SPENCER HAILY,
Dublin.

CITY OF DUNDEE.

QUESTION.	ANSWER.
1. Population of drainage area ?	About 163,000.
2. Approximate volume of sewage discharged per diem ?	About 8,000,000 gallons.
3. Nature of sewage and trade effluents (if any) ?	Principally domestic sewage. Effluent in very small proportion from dye works.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state ?	Yes.
5. If not, to what process of treatment is it first subjected ?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide ?	Sewage discharged at all states of the tide.
7. If not, during what period and at what state of the tide does the discharge take place ?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Sluggish at neap tides, and at the turning of the tides. At spring tides the velocity is between four and five miles per hour. Direction in the flow westwards, and in the ebb eastwards.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	Main outfall practically in the line of jetty at harbour ; (*a*) at low spring tide outfall just covered ; (*b*) at high spring tide, covered to a depth of 15 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	No complaints.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	Sludge banks formed at the main outfalls. They are wholly composed of sand and mud, washed off the streets and roads, and carried by the sewers into the river. As the tide is not strong enough to scour away the deposit, the harbour trustees have to dredge away the banks as they form, to prevent interruption to navigation.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	No.
14. Please furnish any further information of a similar nature which you may think useful.	The foregoing answers apply to the two principal outfalls at the east end of the harbour. There are five other small outfalls to the west of these which give no trouble. All the outfalls discharge into the estuary of the Tay, and it may be stated that there is no trouble or nuisance from the discharge.

EASTBOURNE.

Question.	Answer.
1. Population of drainage area?	Estimated 1904, 45,750. Census 1901, 43,344.
2. Approximate volume of sewage discharged per diem?	2,000,000 gallons, excluding surface water not passing into sewers.
3. Nature of sewage and trade effluents (if any)?	An ordinary effluent of a residential non-manufacturing town.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide.	Yes; either by gravitation or partly by ejectors (Shore's pneumatic system).
7. If not, during what period and at what state of the tide does the discharge take place.	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid. Outgoing tide almost direct to sea.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide.	240 feet. (*a*) 3·26 feet. (*b*) 23·65 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	There are no dwellings near the outfall, but I have received an occasional complaint from a village two or three miles away on the seashore. I have altogether had about four complaints in ten years, and those general, not specific.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by a deposit of sewage solids?	No
13. Have any complaints been made as regards the effects of the discharge on fish life?	No; fishing is good in the immediate vicinity.
14. Please furnish any further information of a similar nature which you may think useful.	———

W. G. Willoughby, M.D. Lond.
Medical Officer of Health.

Eastbourne.

EXMOUTH

Question.	Answer.
1. Population of drainage area?	10,800.
2. Approximate volume of sewage discharged per diem?	2,500 gallons
3. Nature of sewage and trade effluents (if any)?	Ordinary household w.c's. No trade effluent.
A typical analysis should be given, if possible?	———
4. Is the sewage discharged in the crude state?	Yes
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes—though the sewer is probably tide-locked for some hours about high water.
7 If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid—sometimes 5 or 6 knots at springs.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	400 yards—13 ft. below ord. datum. (*a*) 8 ft. below low water. (*b*) 20 ft. below high water at ordinary spring tides.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	There was formerly considerable nuisance before outfall was carried further out into the Channel, from deposit of sewage upon the foreshore, but since alteration there has been little or no nuisance.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Not so much growth now as formerly. There is now very little evidence of decomposing weed. I know the coast well, and have noticed that *ulva latissima* is only plentiful where the water is contaminated with sewage, and am of the opinion that the weed itself is not offensive when decomposing, but that it is weed plus sewage caught in its meshes which gives rise to the nuisance.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful?	The villages of Starcross, Lympstone, and Topsham discharge into the river from one to five miles higher up. The sewers at Starcross discharge through several openings in the sea-wall on to the foreshore. There *ulva latissima* is plentiful and stinks abound, and as the village is situated in a bend of the harbour called "The Bight," there is a good deal of slack water, and the sewage is not rapidly carried away. O. Eaton.

FOLKESTONE.

Question.	Answer.
1. Population of drainage area?	Cheriton 7,898 Folkestone 32,150 Shorncliffe Camp 4,683 44,731
2. Approximate volume of sewage discharged per diem?	2½ million gallons.
3. Nature of sewage and trade effluents (if any)?	Purely household with abundance of spring water. No trade effluent.
A typical analysis should be given, if possible.	Sample taken at 11.15 a.m., March 9, 1904. All numerical results are expressed in grains per gallon :— Colour in 1-inch layer: straw Appearance: very flocculent Smell: distinctly offensive Re-action: alkaline Suspended matter, organic: 26·11 Suspended matter, mineral: 12·32 Suspended matter, total: 38·43 Matter in solution: 63·45 Yielding :— Combined chlorine: 7·28 Nitrogen as nitrates and nitrites: 0·36 Ammonia: 9·11 Albuminoid ammonia: 0·77 Oxygen absorbed in 6 hours: 4·62
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The tide is very sluggish and has a rotatory motion. The position of the outfall is in a small bay on the east side of the harbour and pier, the pier forming the western arm of the bay, which protects it from the full force of the flood tide producing a back water. The ebb tide has no scouring effect at the outfall.
9. At what distance from the shore is the outfall situated; and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outfall is on the foreshore, 1 foot above the level of low (spring) tide. The spring tide rises 20 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	During a prevalence of easterly or south-easterly winds sewage is driven into the harbour and accumulates on the landing stages of the railway pier.

FOLKESTONE.—*continued*

QUESTION.	ANSWER.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing.	There is a certain amount of green sea weed on the rocks in the immediate vicinity of the outfall. The quantity, however, is two small to be appreciable if washed ashore, and has not to my knowledge given rise to nuisance.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——— M. G. Y. BATEMAN, Medical Officer of Health.

COUNTY BOROUGH OF GRIMSBY.

Question.	Answer.
1. Population of drainage area.	63,138 (1901 census).
2. Approximate volume of sewage discharged per diem.	Two million gallons.
3. Nature of sewage and trade effluents (if any).	Ordinary domestic sewage. No trade effluents.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The sewage is discharged into the Humber, about seven miles from the mouth. The current is quick during the outgoing tide, and sluggish or stationary on the incoming.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Outfall about low water, neap tide level, or say 4·75 ft. below ordnance datum; (*a*) low spring tide is 4·25 ft. below outfall; (*b*) high water spring tide is 15·75 ft. above outfall.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	The outfall itself (practically adjoining the Fish Dock) is in the hot weather undoubtedly a nuisance, and the backing up of sewage on the foreshore is a danger to which the attention of this authority has been frequently drawn.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	——
14. Please furnish any further information of a similar nature which you may think useful.	——
	T. Newby, M.D.

HARWICH.

QUESTION.	ANSWER.
1. Population of drainage area ?	9,000.
2. Approximate volume of sewage discharged per diem ?	10 gallons per head of population—90,000 gallons.
3. Nature of sewage and trade effluents (if any) ?	No trade effluent.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state ?	Yes.
5. If not, to what process of treatment is it first subjected ?	— —
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide ?	No. The whole of the sewage is contained in a storage sewer and is discharged through 18 inch C.I. pipes into the sea by opening a penstock one hour after high water.
7. If not, during what period and at what state of the tide does the discharge take place ?	Penstock opened one hour after high water, and—assuming storage sewer to be full—it will take 1½ hours to 2 hours to empty.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Rapid ; direct out to sea, in the direction of the Cork lightship
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	100 feet from the extreme end of stone breakwater in 22 feet water low spring tide, 33 feet high spring tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No
13. Have any complaints been made as regards the effects of the discharge on fish life ?	No.
14. Please furnish any further information of a similar nature which you may think useful	———

HASTINGS.

QUESTION.	ANSWER.
1. Population of drainage area?	67,000.
2. Approximate volume of sewage discharged per diem?	1,050,000 gallons
3. Nature of sewage and trade effluents (if any)	Almost entirely ordinary domestic sewage. All water-closets and many baths.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state.	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No; discharged intermittently.
7. If not, during what period and at what state of the tide does the discharge take place?	Eastern outfall.—Discharge two hours after flood tide commences to flow. Flood tide flows eastward. Western outfall.—Discharge four hours before low water. Ebb tide flows westward.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Eastern outfall.—Flood tide very strong, eastward. Western outfall.—Ebb tide slack, westward.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Eastern outfall about 580 feet; mouth of outfall is 1 foot 9 inches below low water level. High water spring tide about 25 feet 6 inches above invert of outfall. Western outfall about 250 feet from shore. Mouth of pipe above low water level about 8 feet 6 inches, and 15 feet 6 inches below high water spring tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Eastern outfall.—Not to my knowledge. Western outfall.—Very occasional complaint has been made of smell when wind in the west.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you think useful.	Western outfall is about to be considerably lengthened. A. SCARLYN WILSON, Hastings, March 8th, 1904. Medical Officer of Health

HULL.

QUESTION.	ANSWER.
1. Population of drainage area?	About 250,000.
2. Approximate volume of sewage discharged per diem?	12,000,000 gallons in dry weather.
3. Nature of sewage and trade effluents (if any)?	Dilute domestic sewage with a considerable quantity of condensing water from works on River Humber. Trade effluents negligible. Few tenements or small houses built prior to 1903 have w.c.'s.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid, direction at right angles to direction of outfall in both directions (up and down).
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outfalls are in the face of river walls, 9·50 and 10·0 below Ordnance Datum. L.W.O.S.T. is 10·10 below O.D. and H.W.O.S.T. 12·37 above O.D.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No, but the Humber is heavily charged with silt, and, as previously stated, the currents are rapid.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No. There is no considerable growth of sea weed in any part of the Humber.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No
14. Please furnish any further information of a similar nature which you may think useful?	The minimum width of the Humber opposite Hull is 1½ miles and the velocity of tide ranges up to about 7 miles per hour. The sewage is pumped into the Humber at all states of the tide, and so long as the outfall is well submerged the presence of sewage can scarcely be detected at the point of discharge. A. E. WHITE, City Engineer. 27th February, 1904.

ILFRACOMBE.

QUESTION.	ANSWER.
1. Population of drainage area?	About 9,000. During season approximately about 12,000 or 13,000.
2. Approximate volume of sewage discharged per diem?	300,000 gallons to 500,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Strictly domestic sewage.
A typical analysis should be given, if possible.	No analysis has been made; consumption of water about 30 gallons per head.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	Nil.
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	————
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rate of current past outfall at half tide two to three knots. The current runs parallel with the shore for about half a mile each way, always eventually joining the main tidal flow of the Bristol Channel. The current is very variable, and at half tide usually sets in the opposite direction to the main tidal flow. Floats placed in this current are invariably carried out to sea.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	315 lin. yards from H.W.M. 255 „ „ L.W.M. Depth of water 35 ft. 0 in. at L.S.T. „ „ 65 ft. 0 in. at H.S.T.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	Fish are caught and laver collected, and no injurious effects observed from the proximity of the outfalls.
14. Please furnish any further information of a similar nature which you may think useful?	————

ED. SLADE KING,
Medical Officer of Health.

LANCASTER.

Question.	Answer.
1. Population of drainage area?	43,570 estimated to June 30th, 1904.
2. Approximate volume of sewage discharged per diem?	1,500,000 gallons per day estimated exclusive of rainfall.
3. Nature of sewage and trade effluents (if any)?	The sewage is almost wholly domestic. It however contains a small quantity of trade effluent from oilcloth works and a small chemical works. The quantity of sewage discharged into the estuary is estimated at 1,500,000 gallons per diem. This estimate does not include the surface water from the rainfall of the area (3,610 acres) upon which the town is built. The average annual rainfall for Lancaster during the past nine years is 39·60 inches per annum. The River Lune has a drainage area of 418 square miles. The volume of salt water passing up the estuary at each tide at mean tide level is approximately 2,769,000,000 cubic feet. Reckoning two-thirds of the sewage to be discharged in one tide the dilution of the sewage in the estuary is estimated as one gallon of sewage to 17,000 gallons of sea water. Appended will be found copies of analyses made at the request of the Corporation of Lancaster by two analytical chemists. Samples of the river water were taken from the estuary near the sewage outfalls in six different places at three states of the tide.
A typical analysis should be given, if possible.	*See* below, "Report on the Waters of the River Lune, with Analysis."
4. Is the sewage discharged in the crude state?	Yes, but very much diluted.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The velocity of the tides is about 5 knots per hour. The direction of the tides is at right angles to the sewage outfalls.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	There are seven outlets for the sewage into the estuary. Six of these outlets are practically at low water. The seventh (the Stodday sewer) is eight feet above low water.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No, I have neither heard of nor seen any.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	I have not been able to find any of these sea weeds on the banks of the estuary. Certainly no nuisance ever arises in hot weather from the weeds being washed ashore and decomposing.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	On July 8th, 1904, I visited all the sewer outlets, and passed along the whole length of the estuary at low water in a boat. I inspected the mussel beds five miles below Lancaster, and I noted the condition of the river. I found no evidence of any pollution or deposit of sewage matter. No deposits of sewage were to be found, or any evidence of their existence at any point.

LANCASTER—*continued.*

QUESTION.	ANSWER.
13. Have any complaints been made as regards the effects of the discharge on fish life?	In July, 1899, the Lune Fishery Board made complaint to the Local Government Board, but that Board took no action in the matter, having been furnished with a report from the Borough Engineer of Lancaster, and separate analyses from two analytical chemists.
14. Please furnish any further information of a similar nature which you may think useful?	As far as can be ascertained, there is a plentiful supply of salmon and other fish in the estuary. The Lune is a noted salmon river, and the fish are in great demand. At the upper end of the estuary is a weir, which the fish have great difficulty in passing. A successful fishery exists in the upper portion of the estuary.

G. R. PARKER,

Lancaster. Medical Officer of Health.

REPORT ON THE WATERS OF THE RIVER LUNE, WITH ANALYSES.

[COPY.]

Analytical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Report on the water of the River Lune taken at a mean tide on July 28th, 1899, in mid-stream opposite the places named in the certificates.

The chlorides at low tide are, in the cases of the samples taken at Scaleford and west outfall, in such amounts as might be found in some drinking waters, and in any case are partly derived from the sea water.

In the case of the other three samples taken at low tide at halfway between west outfall and Stodday, at Stodday, and half a mile below Stodday, the high amount of chlorides distinctly points to admixture with sea water.

The high tides and half-tides were very high in chlorides (common salt), and were practically sea water.

The chlorides of the half-tides and full tides are not stated in the certificates, as it would be only dealing with sea water.

The Free and Albuminoid Ammonia.

The low tides, where the most characteristic yield of sewage contamination should be expected, shows an average of 0·011 parts per 100,000, in the case of the free ammonia, and 0·023 parts per 100,000 in the case of the albuminoid ammonia.

The half-tide averages are: Free ammonia, 0·016 parts per 100,000; albuminoid ammonia, 0·020 parts per 100·000.

The high tide averages are: Free ammonia, 0·012 parts per 100,000; albuminoid ammonia, 0·013 parts per 100,000.

These amounts of free and albuminoid ammonia are about double of those found in many samples of water for domestic use.

According to Wanklyn (Sewage Analysis, 1899), in the purified effluent from the Croydon sewage farm, taken at the lower farm outfall, Beddington Farm, the free ammonia is 0·08 parts per 100,000 and the albuminoid ammonia 0·044 parts per 100,000, and at field outfall Beddington Farm, the free ammonia = 0·02 parts per 100,000; albuminoid ammonia, 0·044 parts per 100,000.

The ammonia (free or albuminoid) found in the various samples taken by myself from the River Lune in mid-stream opposite the different sewage outfalls, shows a much smaller quantity of ammonia, either free or albuminoid, than even the purified effluent of Beddington Farm.

None of the samples gave any indication of nitrogen as nitrites and nitrates; they were entirely absent in all cases.

When impurified sewage is allowed to flow into a river, and the free ammonia is greater than 0·12 parts per 100 000, the conditions are probably objectionable.

In this case there is at low tide (when the largest amount of sewage would be expected to be found in the river water) only about one-tenth that amount. At half-tides and full tides the samples gave results which practically identified them with ordinary sea water. It is my opinion that such a small amount of ammonia is quite impossible to cause injury to the fish in the river, as it is far below that standard which is supposed to cause injury to people living on the river bank, and the small amount of ammonia found would indicate, moreover, that the amount of raw sewage passed into the River Lune is so many times less in volume than the water of the river that it can have no possible effect whatever on the life of the fish contained therein.

J. STEWART REMINGTON,
Consulting Chemist.

August 8th, 1899.

[COPY.]

Low tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Scaleford," low tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample with the following results:—

Total solids - -	18·5	grains per gallon.
Chlorine as chlorides	5·2	grains per gallon.
,, ,, -	7·42	parts per 100,000.
,, ,, -	74·2	parts per 1,000,000.
Free ammonia -	0·0056	grains per gallon.
,, ,, -	0·008	parts per 100,000.
,, ,, -	0·08	,, ,, 1,000,000.
Albuminoid ammonia	0·0175	grains per gallon.
,, ,,	0·025	parts per 100,000.
,, ,,	0·25	parts per 1,000,000.

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

LANCASTER—*continued.*

[COPY.]

Half-tide. Chemical Laboratory.
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Scaleford," half-tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Total solids and chlorides (common salt) not stated, as the samples were practically sea water.

Free ammonia - 0·01498 grains per gallon.
,, ,, - 0·0214 parts per 100,000.
,, ,, - 0·214 parts per 1,000,000.

Albuminoid ammonia 0·01764 grains per gallon.
,, ,, 0·0252 parts per 100,000.
,, ,, 0·2520 parts per 1,000,000.
Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

High tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Scaleford," high tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·0168 grains per gallon.
,, ,, - 0·024 parts per 100,000.
,, ,, - 0·24 parts per 1,000,000.

Albuminoid ammonia 0·014 grains per gallon.
,, ,, 0·020 parts per 100,000.
,, ,, 0·200 parts per 1,000,000.
Nitrogen as nitrites and nitrates: Absent.

J. STEWART REMINGTON.

[COPY.]

Low tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "West outfall," low tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Total solids - 19·7 grains per gallon.
Chlorine as chlorides 6·0 grains per gallon.
,, ,, 8·57 parts per 100,000.
,, ,, 85·7 parts per 1,000,000.

Free ammonia - 0·00364 grains per gallon.
,, ,, - 0·0052 parts per 100,000.
,, ,, - 0·052 parts per 1,000,000.

Albuminoid ammonia 0·01568 grains per gallon.
,, ,, 0·0224 parts per 100,000.
,, ,, 0·224 parts per 1,000,000.
Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

Half-tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "West outfall," half-tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·01498 grains per gallon.
,, ,, - 0·0214 parts per 100,000.
,, ,, - 0·2140 parts per 1,000,000.

Albuminoid ammonia 0·0161 grains per gallon.
,, ,, 0·0230 parts per 100,000.
,, ,, 0·230 parts per 1,000,000.
Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

High tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "West outfall," high tide, received from the Lancaster Corporation on July, 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·01218 grains per gallon.
,, ,, - 0·0174 parts per 100,000.
,, ,, 0·1740 parts per 1,000,000.

Albuminoid ammonia 0·0126 grains per gallon.
,, ,, 0·018 parts per 100,000.
,, ,, 0·180 parts per 1,000,000.
Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

Low tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Halfway between west outfall and Stodday," low tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Total solids - - 228·5 grains per gallon.
Chlorine as chlorides 129·2 grains per gallon.
,, ,, 156 parts per 100,000.
,, ,, 1560 parts per 1,000,000.

Free ammonia - 0·00742 grains per gallon.
,, ,, - 0·0106 parts per 100,000.
,, ,, - 0·106 parts per 1,000,000.

Albuminoid ammonia 0·0161 grains per gallon.
,, ,, 0·023 parts per 100,000.
,, ,, 0·23 parts per 1,000,000.
Nitrogen as nitrates and nitrites: None.

J. STEWART REMINGTON.

[COPY.]

High tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Halfway between west outfall and Stodday," half-tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - - 0·014 grains per gallon.
,, ,, - 0·020 parts per 100,000.
,, ,, - 0·200 parts per 1,000,000.

Albuminoid ammonia 0·014 grains per gallon.
,, ,, 0·020 parts per 100,000.
,, ,, 0·200 parts per 1,000,000.
Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

LANCASTER—*continued.*

[COPY.]

High tide. Chemical Laboratory.
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Halfway between west outfall and Stodday," high tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·0028 grains per gallon.
,, ,, - 0·004 parts per 100,000.
,, ,, - 0·040 parts per 1,000,000.

Albuminoid ammonia 0·007 grains per gallon.
,, ,, 0·010 parts per 100,000
,, ,, 0·100 parts per 1,000,000

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

Low tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Stodday," low tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Total solids - - 417·0 grains per gallon.
Chlorine as chlorides 205·8 grains per gallon.
,, ,, 294 parts per 100,000.
,, ,, 2940 parts per 1,000,000.

Free ammonia - - 0·0112 grains per gallon.
,, ,, 0·016 parts per 100,000.
,, ,, - 0·16 parts per 1,000,000.

Albuminoid ammonia 0·1708 grains per gallon.
,, ,, 0·0244 parts per 100,000.
,, ,, 0·244 parts per 1,000,000

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

Half-tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river tide marked "Stodday," half-tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·00742 grains per gallon.
,, ,, - 0·0106 parts per 100,000.
,, ,, - 0·106 parts per 1,000,000.

Albuminoid ammonia 0·01218 grains per gallon.
,, ,, 0·0174 parts per 100,000.
,, ,, 0·174 parts per 1,000,000.

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

High tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Stodday," high tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·00742 grains per gallon.
,, ,, - 0·0106 parts per 100,000.
,, ,, - 0·106 parts per 1,000,000.

Albuminoid ammonia 0·0063 grains per gallon.
,, ,, 0·009 parts per 100,000.
,, ,, 0·09 parts per 1,000,000.

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

Low tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Half-mile below Stodday," low tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Total solids - - 558·8 grains per gallon.
Chlorine as chlorides 290·5 grains per gallon.
,, ,, 415 parts per 100,000.
,, ,, 4150 parts per 1,000,000.

Free ammonia - 0·01302 grains per gallon.
,, ,, - 0·0186 parts per 100,000.
,, ,, - 0·186 parts per 1,000,000.

Albuminoid ammonia 0·0161 grains per gallon.
,, ,, 0·023 parts per 100,000.
,, ,, 0·23 parts per 1,000,000.

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

Half-tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Half-mile below Stodday," half-tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·0056 grains per gallon.
,, ,, - 0·008 parts per 100,000.
,, ,, - 0·080 parts per 1,000,000.

Albuminoid ammonia 0·1008 grains per gallon.
,, ,, 0·0144 parts per 100,000.
,, ,, 0·1440 parts per 1,000,000.

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

[COPY.]

High tide. Chemical Laboratory,
Corporation Street, Lancaster.
August 8th, 1899.

Certificate of Analysis.

Sample of river water marked "Half-mile below Stodday," high tide, received from the Lancaster Corporation on July 28th, 1899.

I certify that I have examined the above sample, with the following results:—

Free ammonia - 0·00182 grains per gallon.
,, ,, - 0·0026 parts per 100,000.
,, ,, - 0·026 parts per 1,000,000.

Albuminoid ammonia 0·0049 grains per gallon.
,, ,, 0·007 parts per 100,000.
,, ,, 0·07 parts per 1,000,000.

Nitrogen as nitrites and nitrates: None.

J. STEWART REMINGTON.

LANCASTER.—*continued.*

RESULT OF ANALYSES OF 15 SAMPLES OF WATER TAKEN FROM THE RIVER LUNE ON 25TH AUGUST, 1899.

	Grains per gallon.		Oxygen required to oxydise organic matters :		Free Ammonia	Albuminoid Ammonia.
	Total Solids.	Combined Chlorine—Sodium Chloride.	In 15 minutes.	In 4 hours.		
No. 1—Opposite Scale Ford :						
Low water, 5.40 a.m.	1176·0	990·9	·089	·181	·0315	·0175
Half tide, 12.23 p.m.	623·0	511·9	·041	·196	·0350	·0210
High tide, 1.50 p.m.	2191·0	1879·6	·038	·155	·0245	·0175
No. 2—West Outfall :						
Low water, 5.45 a.m.	1417·5	1203·9	·134	·149	·0315	·0210
Half tide, 12.18 p.m.	612·5	518·9	·034	·191	·0280	·0210
High tide, 1.54 p.m.	2254·0	1957·4	·027	·134	·0245	·0140
No. 3—Half way between West Outfall and Stodday Sewer :						
Low water, 6.5 a.m.	1764·0	1515·1	·072	·154	·0280	·0210
Half tide, 12.8 p.m.	2030·0	1748·6	·037	·187	·0245	·0175
High tide, 2.30 p.m.	2555·0	2203·1	·011	·121	·0210	·0140
No. 4—Opposite Stodday Outfall.						
Low water, 7.15 a.m.	1788·5	1552·0	·074	·140	·0315	·0280
Half tide, 12 noon	2275·0	1992·2	·034	·169	·0210	·0175
High tide, 2.45 p.m.	2548·0	2203·1	·021	·103	·0175	·0140
No. 5—Half mile below Stodday Sewer Outfall, opposite Fish Pond, Ashton Estate :						
Low water, 7.23 a.m.	1872·5	1588·8	·079	·190	·0350	·0227
Half tide, 11.65 a.m.	2294·0	2104·8	·029	·155	·0105	·0245
High tide, 2.50 p.m.	2513·0	2203·1	·014	·114	·0140	·0175

The above figures prove the samples to consist very largely of sea water, in some cases almost entirely. As regards freedom from sewage pollution all the samples may be regarded as extremely satisfactory ; indeed, they are quite equal in point of organic purity to many drinking waters, and contain nothing which is likely to be injurious to fish.

(Signed) ROWLAND WILLIAMS, F.I.C., F.C.S., Member of Council of the Society of Public Analysts.

CITY OF LIVERPOOL.

Question.	Answer.
1. Population of drainage area?	645,400; draining direct into the River Mersey.
2. Approximate volume of sewage discharged per diem?	27,500,000 gallons.
3. Nature of sewage and trade effluents (if any)?	———
A typical analysis should be given, if possible.	No analysis made.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	No analysis made.
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	———
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	———
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	———
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	———
13. Have any complaints been made as regards the effects of the discharge on fish life?	———
14. Please furnish any further information of a similar nature which you may think useful.	———
	JAMES BRODIE.

LLANDUDNO.

QUESTION.	ANSWER.
1. Population of drainage area?	Resident population, 9,359. Resident and visiting population estimated at 28,077.
2. Approximate volume of sewage discharged per diem?	On resident population, 235,000 gallons per day. On resident and visiting population, 700,000 gallons per day.
3. Nature of sewage and trade effluents (if any)?	Almost entirely domestic. No offensive trades.
A typical analysis should be given, if possible.	REPORT OF ANALYST UPON TWO SAMPLES OF SEWAGE FROM LLANDUDNO.

——	Sample A.	Sample B.
Free and saline ammonia - - - -	1·60 per 100,000	1·02 per 100,000
Albuminoid ammonia - - - - -	0·23 ,,	0·28 ,,
Oxygen absorbed in 2 hours at 80 deg. F.	13·92 ,,	17·46 ,,
Chlorine - - - - - - - -	?14·0 ,,	?25·50 ,,
Total solids - - - - - -	?13·0 ,,	?12·8 ,,
Bacteriological examination :— Number of organisms per c.c. - -	5,000,000	3,000,000
Coli present per c.c. in 48 hours - -	100,000 at least	100,000 at least
Enteritidis sporogenes in 48 hours -	100	100

(Signed) F. N. MENZIES, M.D.,
Public Health Laboratory,
King's College, London.

QUESTION.	ANSWER.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	At spring tide the discharge commences about 1½ hours after high water, and continues until 1½ hours before the next high water. At neap tides the discharge commences about 2 hours after high water, and continues until 2 hours before the next high water. Under the worst conditions, viz., at neap tides, the outfall is tide-locked for about 7½ hours, during which period the sewage is stored in a 6 feet by 4 feet tank sewer.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Medium, and running north-west.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high spring tide?	The outfall at present is 1,217 yards in length, and the point of discharge is situate 1,217 yards in a W.N.W. direction from the west toll gate of the Marine Drive and 622 yards in a southerly direction from the shore. The outlet is dry at low spring tides, and at high spring tides is 23 feet under water. A further extension seawards for a length of 278 yards is in course of construction. When this is completed the outlet will be 1,495 yards in length in a W.N.W. direction, and 667 yards in a southerly direction from the shore, and the discharge end will be dry at the lowest spring tides, and at high spring tides will be covered by 24 feet 3 inches of water.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Complaints have been received to the effect that a portion of the floatable solids have at times reached the shore on the flood tides, and on this account the outfall is being extended 278 yards further seawards, which it is hoped may effectually prevent this. The whole of the outfall is at the back of the town, and the adjoining land consists of mountain pasture land of a barren and rocky nature.

LLANDUDNO—*continued.*

QUESTION.	ANSWER.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing.	There is a considerable growth of sea weed along the coast, but no complaints have arisen on this account. There is none near the end of the outfall.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	—

E. PALEY STEPHENSON, Assoc. M Inst. C.E.,
Engineer to the Llandudno Urban District Council.

February 24th, 1904.

LLANDUDNO JUNCTION.

Question.	Answer.
1. Population of drainage area?	935.
2. Approximate volume of sewage discharged per diem?	20,570 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic.
A typical analysis should be given, if possible?	Sample analysed by Dr. F. N. Menzies, King's College Laboratory :— Fœcal odour well marked. Free and saline ammonia - - - - - 0·50 per 100,000. Organic ammonia - - - - - - 0·15 „ 100,000. Chlorine - - - - - - - 6 „ 100,000. Nitrogen as nitrates and nitrites - - - Very slight traces, inestimable. Oxygen absorbed in two hours at 80° F. - 2 parts per 100,000. Solid residue - - - - - - 50 „ 100,000.* * Almost entirely non-mineral, marked charring of deposit residue. I am of opinion that, taking all the above factors in consideration, this is a satisfactory sewage effluent. (Signed) F. N. Menzies.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible?	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Almost at all times.
7. If not, during what period and at what state of the tide does the discharge take place?	At all times, excepting for short periods when the sewers are tide-locked at high tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rather sluggish (not rapid at the point of outfall, but rapid, at times, six or seven knots per hour 300 yards away).
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	On the shore, 300 yards above low water mark. Only covered at high tide. The depth of water at high (spring) tide is about 8 ft., and at low (spring) tide it is uncovered.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.

LLANDUDNO JUNCTION—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful?	——

P. FRASER, M.D.,

Carnarvon. Medical Officer of Health.

LLANFAIRFECHAN.

Question.	Answer.
1. Population of drainage area ?	Winter, 2,200. Summer, 5,200.
2. Approximate volume of sewage discharged per diem.	Winter 67,200 gallons. Summer, 158,400 gallons.
3. Nature of sewage and trade effluents (if any) ?	Domestic.
A typical analysis should be given, if possible.	— —
4. Is the sewage discharged in the crude state ?	Yes.
5. If not, to what process of treatment is it first subjected ?	—
A typical analysis of the treated sewage should be given, if possible.	—
6. Is the sewage or treated effluent discharged at all states of the tide ?	Yes, excepting at high tide when outfall is tide-locked.
7. If not, during what period and at what state of the tide does the discharge take place ?	—
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Sluggish. Incoming tide and out-going tide is along coast.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high spring tide ?	1650 yards. (*a*) Exposed at low (spring) tide. (*b*) 20 feet of water at high (spring) tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore.	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	No.
14. Please furnish any further information of a similar nature which you may think useful ?	The system of sewers is the Shone Hydro Pneumatic. There is a large sewer tank at upper end of main outfall, to hold 48,000 gallons, for the storage and discharge of part of the sewage during the ebbing tides. P. Fraser, M.D., Carnarvon. Medical Officer of Health.

LLANRWST AND TREFRIW.

Question.	Answer.
1. Population of drainage area?	Llanrwst, 2,650. Trefriw, 800.
2. Approximate volume of sewage discharged per diem?	Outlet of sewers, 12-inch earthenware pipe. Approximately 79,500 and 24,000 gallons per day respectively.
3. Nature of sewage and trade effluents (if any)?	Ordinary house disposal. One small tannery and one small brewery at Llanrwst.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid at both outflows. The direction of the river to which it is disposed.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	In centre of river, at low tide simply covering the outlet; at high tide about 1 foot at Llanrwst and 6 feet at Trefriw.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Yes, to a small extent, in dry seasons.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	It sometimes occurs in dry seasons, but is always washed away by floods.
13. Have any complaints been made as regards the effects of the discharge on fish life?	The water bailiff has repeatedly complained of the injurious effect of the discharged sewage on fish life.
14. Please furnish any further information of a similar nature which you may think useful.	———

R. H. Williams,
Surveyor and Sanitary Inspector, Trefriw

Per Dr. Fraser.

LONDONDERRY (COUNTY BOROUGH).

QUESTION.	ANSWER.
1. Population of drainage area?	Estimated 41,397.
2. Approximate volume of sewage discharged per diem?	Cannot say, as sewers convey rain water—storm water in fact; only one system for all liquid refuse.
3. Nature of sewage and trade effluents (if any)?	Above answer will explain.
A typical analysis should be given, if possible.	No analysis was ever made to my knowledge.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it at first subjected?	———
A typical analysis of the treated sewage should be given, if possible?	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid; direction confined to course of river.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	I should explain that for some distance above and below the city the foreshore has been filled in to such a depth that vessels of considerably over 1,000 tons can anchor at the quay along the whole course, and therefore the sewage is always emptied into about 13 ft. of water at (low) spring tides.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No. Have made enquiries outside Borough boundary, and am informed no nuisance was complained of.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	A dredger is employed constantly by the Port and Harbour Board dredging the river for the purpose of navigation, so no banks or anything else is allowed to form.
13. Have any complaints been made as regards the effects of the discharge on fish life?	Not to my knowledge.
14. Please furnish any further information of a similar nature which you may think useful.	———
	P. H. FERGUSSON. Medical Officer of Health.

LOWESTOFT, SUFFOLK.

QUESTION.	ANSWER.
1. Population of drainage area?	About 31,000.
2. Approximate volume of sewage discharged per diem?	620,000 gallons (surveyor's estimate).
3. Nature of sewage and trade effluents (if any)?	Domestic sewage. Brine from herring gutting yards (principally from September to January). Certain amount of organic matter from fish offal.
A typical analysis should be given, if possible?	No analysis of the effluent has ever been made, to my knowledge.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid; 6 hours ebb and flow. Direction of ebb, north-east.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	230 feet from shore. (*a*) 15 feet low water, spring tide. (*b*) 22 feet high water, spring tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	There is some growth of *enteromorpha* on sheltered positions of the wooden groynes along the north beach. I have seen no specimens of *ulva latissima*, and it is doubtful if this species could ever exist in abundance on so exposed a coast. In fact, the shifting nature of the foreshore and the constant exposure of the coast line to heavy seas render the conditions very unsuitable for luxuriant growth of green sea weeds. No nuisance has ever been experienced, and I should think it is very doubtful whether any nuisance can ever be anticipated from the decay of sea weeds in the neighbourhood of the outfall on the north beach.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No complaints have ever been made to my knowledge. The members of the local Sea Angling Society, whom I have consulted, are not aware of any deleterious effect. The fact that fishing with handlines is successfully practised from the beach in the neighbourhood of the sewage outfall inclines one to the belief that no serious effects can have been experienced.
14. Please furnish any further information of a similar nature which you may think useful.	The outfall discharges at the bed of the ocean. It receives all the drains connected with the public sewers, except (1) a small district known as Bevan and Tonning Streets, which discharges into the north side of the fairway of the harbour, east of the bridge; (2) a small district known as the Esplanade, which discharges into the south side of the fairway of the harbour, east of the bridge.

A. MARSHALL, D.P.H.

Lowestoft. Medical Officer of Health.

MARGATE, KENT.

Question.	Answer.
1. Population of drainage area?	Varies from 28,000 to 110,000.
2. Approximate volume of sewage discharged per diem?	Varies from 840,000 gallons to 1,250,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic—except for a very small amount of brewery waste.
A typicel analysis should be given, if possible?	—
4. Is the sewage discharged in the crude state?	
5. If not, to what process of treatment is it first subjected?	—
A typical analysis of the treated sewage should be given if possible?	—
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	—
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid. Flood tide, east to west. Ebb tide, west to east.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	600 yards from shore. Sewage outfall invert is 12 feet below O.D. H.W.O.S.T. = 9·30 A.O.D. L.W.O.S.T. = 6·67 B.O.D.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore.	None whatever; both tides tend to carry sewage away from shore.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Yes. Enteromorpha Intestinalis, Ulva Latissima, and Cladophora supertoris. Before there was any sewer, there was frequently a nuisance in summer time; since the district has been drained this has not been increased. I need hardly say, that, even before there was any sewage, the visitors and others were convinced that the bad smell was due to defective drains.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids.	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful?	This is one of the most satisfactory outfalls on the English coast. It has been in existence 13 years and has never given a moment's trouble.

BERTRAM THORNTON,
Margate. Medical Officer of Health.

MENAI BRIDGE.

Question.	Answer.
1. Population of drainage area?	1,700.
2. Approximate volume of sewage discharged per diem?	50,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary sewage, very foul at times.
A typical analysis should be given, if possible.	No analysis made.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No; there are ball valves at the four outfalls, which retain the sewage during a certain period in the sewers.
7. If not, during what period and at what state of the tide does the discharge take place?	The discharge takes place about three hours after high water till about three hours and a half after low water.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	At Outfalls Nos. 1, 2 and 3 the tides are very rapid, as high as eight miles an hour. At Outfall No. 4 the tide is rather sluggish, about two and a half to three miles at the limit, and at certain states of the tide it is practically stagnant.
9 At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	No. 1, about 8 yards. „ 2, „ 12 „ „ 3, „ 120 „ „ 4, „ 400 „ (*a*) Depth of water at No. 1, dry. „ „ „ „ 2, „ „ „ , „ 3, „ „ „ „ „ 4, „ (*b*) „ „ „ „ 1, about 10 feet. „ „ „ 2, „ 18 „ „ „ „ „ 3, „ 16 „ „ „ „ „ 4, „ 19 ,
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Yes, complaints were made that the sludge from No. 4 was washed back into the bay, and was deposited on the foreshore. This was abated by extending the sewer.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.

Menai Bridge.—*continued.*

Question	Answer.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Yes, at No. 4 Outfall but very little
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	———
	R. Arthur Thomas, Per Dr. Fraser. Surveyor.

MIDDLESBOROUGH (YORKSHIRE).

QUESTION.	ANSWER.
1. Population of drainage area?	Drainage area 1,723 acres. Population last census 91,302.
2. Approximate volume of sewage discharged per diem?	Dry weather flow 1,800,000 gallons.
3. Nature of sewage and trade effluents (if any)?	There are no trade effluents as understood as such. The trade of Middlesborough is the smelting of iron and allied industries, which does not involve the production of trade effluents; besides there are very few water closets, all the excrementatious matter being collected in pan closets and sent out to the farms in the district, or otherwise disposed of. There is no duplicate system of sewers, but there are three storm outfalls in addition to the main outfall. Practically all storm water goes into the sewers.
A typical analysis should be given, if possible.	*Analysis—* Organic, 29·6000. Inorganic, 20·800. Free ammonia, 0·2500. Albuminoid, 9·0400. Chlorine, 14·5000.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No. The main outfall begins to discharge at half tide. A pumping plant is now being erected, capable of pumping 60,000 gallons per minute, to lift the sewage at all stages of the tide.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Varying from one to three knots.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The main outfall discharges into the Tees Estuary, which varies in width from 700 feet to over two miles. The invert of the main outfall is 6·60 below ordnance datum. Bolckow's storm outfall, 4·40 below ordnance datum. Samuelson's „ 3·73 „ „ „ Ormesby Beck „ 3·50 above ordnance datum. The ordinary spring tides vary 17 feet between high and low water.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Never heard of any, nor has any complaints been received at any time. The main outfall was constructed in 1878.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No. I have never seen any in the Tees Estuary, or on the foreshore to the north and south of the harbour mouth.

MIDDLESBOROUGH (YORKSHIRE)—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No. The scour caused by the enormous quantity of fresh water coming down the Tees effectually prevents any such formation, the watershed of the Tees being 744 square miles.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No. The very fact of salmon passing up and down the Tees in large numbers is a very good proof that the quantity of sewage compared with the flow of the Tees is infinitesimal.
14. Please furnish any further information of a similar nature which you may think useful?	The Borough of Darlington and the adjoining Boroughs of Stockton-on-Tees and Thornaby-on-Tees discharge the whole of their sewage untreated into the Tees above Middlesborough. There are several other towns and villages in the upper reaches discharging sewage into the Tees.

CHARLES V. DINGLE,
Medical Officer of Health.

Middlesborough.

MILFORD HAVEN (HAKIN).

Question.	Answer.
1. Population of drainage area?	About 670.
2. Approximate volume of sewage discharged per diem?	About 1,700 gallons.
3. Nature of sewage and trade effluents (if any)?	House slops and contents of water closets. No trade effluents Only a small portion of the district is at present sewered.
A typical analysis should be given, if possible.	
4 Is the sewage discharged in the crude state?	Yes.
5 If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	During ebb tide and at low water the outfall sewer is provided with a tide flap, which prevents any discharge during flow tides.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Fairly rapid, with an average rise and full of about 13 feet. Direction of flow, east and west.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Outfall at bottom of embankment wall of docks. (*a*) About 7 feet above low water; (*b*) about 17 feet below high tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Not to any appreciable extent. The amount of solid matter at present discharged is so small that it is thoroughly dissolved and carried away at every tide; but should a greater number of houses be connected, it will be necessary to have the outfall carried out beyond low spring tide mark.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	None.
13. Have any complaints been made as regards the effects of the discharge on fish life?	I have never heard of any, and, as previously stated, the amount of sewage discharged is not, in my opinion, sufficient to have detrimental effect on fish life.
14. Please furnish any further information of a similar nature which you may think useful.	———

W. S. Griffith, M.B.,
Medical Officer of Health,
Milford Haven Urban District Council.

NEWPORT (MON.).

Question.	Answer
1. Population of drainage area?	70,217.
2. Approximate volume of sewage discharged per diem?	Dry weather flow 2,000,000 gallons
3. Nature of sewage and trade effluents (if any)?	Domestic sewage Effluent from Ironworks, Chemical Manure Works, and Rubber Works.
A typical analysis should be given, if possible.	—— ——
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible?	————
6. Is the sewage or treated effluent discharged at all states of the tide?	Sewers are tide-locked during certain hours daily; amount depending upon nature of the tides, whether "spring" or "neap."
7. If not, during what period and at what state of the tide does the discharge take place?	————
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Tides are very rapid in the river, varying from four and five to six and eight knots per hour. Direction of flow of tide is at right angles to outlet of sewers.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide.	Outfalls are situated on the river bank.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore.	In one case there was a considerable amount of effluvium arising from the water into which the "Tredegar Pill" outfall flowed, owing to the existence of a narrow bay at that point, and consequent stagnation. This outfall has been taken out into the river proper, with good results. In one case where main outfall sewer receives branch sewers which have defective gradients, and in which accumulations occur the smell at outfall is offensive, but not more so than that which, unfortunately, frequently arises from the street ventilators.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	None.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No. The rapid rise and fall of the tide stirs up the mud thoroughly, and oxidises organic matter very satisfactorily. The bed of the river gets a thorough exposure to the atmosphere twice daily, and thus an intermittent process of oxidisation occurs.

NEWPORT (MON.)—*continued.*

QUESTION.	ANSWER.

RIVER WATER ANALYSIS. PARTS PER 100,000.

—	Free NH_3.	Albuminoid NH_3.	Nitrates and Nitrites.	Oxygen absorbed.	Chlorides.
Sample I (4 hours after high water)	·063	·041	·189	·172	607
" II ?	·034	·081	·170	?	487
" III ?	·027	·030	·281	·320	1,063
" IV (1½ hours after high water)	·020	·056	·267	·080	1,017
" V ?	·013	·043	·063	·200	959

QUESTION.	ANSWER.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No. The fishing (salmon) up the river is far better than it has been for years.
14. Please furnish any further information of a similar nature which you may think useful?	The pollution of the Usk above Caerleon by tributary rivers containing minerals and sewage does, I understand, interfere with the passage of salmon up stream at neap tides. This is probably due to both the minerals present and the want of oxygen owing to the inhibitive action of the minerals in the bacterial purification of the stream. J. HOWARD JONES M.D., D.Sc.

PENMAENMAWR.

Question.	Answer.
1. Population of drainage area?	3,500.
2. Approximate volume of sewage discharged per diem?	Not ascertained. Say, 105,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic sewage.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes, excepting when sewer is tide-locked.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid flow to open sea with receding tide, and also to Estuary of Conway with incoming tide.
9. At what distance from the shore is the outfall situated and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	1,000 feet from shore. Outfall is above low water mark of ordinary spring tides.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No trace.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	The comparatively small amount, and the nature of the sewage discharged and the position of the outfall, leave no ground for complaint or cause for nuisance. P. Fraser, M.D., Carnarvon. Medical Officer of Health.

PENRHYNSIDE.

Question.	Answer.
1. Population of drainage area?	550.
2. Approximate volume of sewage discharged per diem?	6,600 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary domestic.
A typical analysis should be given, if possible.	REPORT OF ANALYST. Fœcal odour well marked. Free and saline ammonia - - - - - 0·8 per 100 000 Organic ammonia - - - - - - 0·250 „ Chlorine - - - - - - - - 8·5 „ Nitrogen as nitrates and nitrites - - Merely traces, inestimable. Oxygen absorbed in 2 hours at 80 deg. F. - 1·03 per 100,000. Solid residue - - - - - - - 27 parts per 100,000. Distinct evidence of much charring. On the whole, I am of opinion that this is a satisfactory sample of sewage effluent. (Signed) F. N. MENZIES, M.D., King's College Public Health Laboratory.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Practically at all times.
7. If not during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid. The usual tidal currents between the Little Orme and Colwyn Bay.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	At low water mark. Depth of water (*a*) at low (spring) tide, outfall uncovered; (*b*) at high (spring) tide, 18 to 20 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore.	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.

PENRHYNSIDE—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——— P. FRASER, M.D., Medical Officer of Health. Carnarvon.

PENZANCE.

Question.	Answer.
1. Population of drainage area?	13,494.
2. Approximate volume of sewage discharged per diem?	With storm waters about 325,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Excremental matters, slop and storm waters No trade effluents of importance
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Medium N.E.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	There are three outfalls, each about 300 yards from the shore). (*a*) Two are just open at low spring tides ; (*b*) about 18 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Sewage occasionally carried into the harbour (tidal).
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	On the bedof the harbour ; offensive in hot weather.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No. (*N.B.*—There are no oyster-beds.)
14. Please furnish any further information of a similar nature which you may think useful?	The only tidal waters in Penzance are of the sea and harbour There are no rivers.

R. D Boase,
Medical Officer of Health.

Rosevean Cottage, Penzance,
February 25th, 1904.

PLYMOUTH.

Question.	Answer.
1. Population of drainage area?	Estimated 113,300.
2. Approximate volume of sewage discharged per diem?	About 4,500,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Practically no trade effluents.
A typical analysis should be given, if possible.	No analysis has been made.
4. Is the sewage discharged in the crude state?	Yes; except from a district recently annexed, and the sewage therefrom is now proposed to be diverted, as the tanks have always been a nuisance.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	On ebb tide. Main intercepting scheme of drainage is now nearly completed, and by it 92 per cent. of drainage area will be discharged between high water and one hour before low water. The remaining 8 per cent. will discharge till low water, it being a very low district.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	At point of proposed new outfall and Fisher's Nose the tidal currents are rapid. The first has an easterly direction and the latter west-south-westerly, until joining the former, where both take south-easterly direction to sea by eastern end of Plymouth Breakwater.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	At present there are four points of discharge— (1) Effluent from annexed area, and discharging in tidal estuary about 4 feet *above* low (spring) tide and 12 feet below high (spring) tide. (2) Discharge into tidal estuary in Deadman's Bay. Cattewater about 2 feet above low (spring) tide and 14 feet below high (spring) tide and close in shore. (3) Discharge into sea (Plymouth Sound) about 90 yards from shore into 30 feet below (*a*). (4) Discharge into sea (Plymouth Sound) near Millbay Pier (*a*) 4 feet; (*b*) 20 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Nuisance has been caused from the deposit of sewage on foreshore in Deadman's Bay and an annoyance at Millbay, and it is proposed to dispense with the outfalls at these points and discharge into deep water—about 95 feet below low water. Where the sewage discharges in the Sound at mouth of Cattewater, into 30 feet of water, no annoyance has been caused.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	———

PLYMOUTH—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Except where the sewage discharges in the bays—(2) and (4) paragraph 9—there is no evidence of sludge banks having been formed.
13. Have any complaints been made as regards the effects of the discharge on fish life?	None. Some of the finest bass have been caught near the outfalls.
14. Please furnish any further information of a similar nature which you may think useful.	———
	F. M. WILLIAMS, M.R.C.S., L.R.C.P., D.P.H., Medical Officer of Health, Borough and Port of Plymouth.

N.B. According to our observations there was abundance of *ulva latissima* in the Plym near one of the outfalls in 1904.

E. A. L.
W. E. A.

POOLE, DORSET.

QUESTION.	ANSWER.
1. Population of drainage area?	20,500 about.
2. Approximate volume of sewage discharged per diem?	500,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Chiefly domestic.
A typical analysis should be given, if possible.	—— ——
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	————
A typical analysis of the treated sewage should be given, if possible.	————
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	————
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Very rapid; east at the flood, west at the ebb.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	2,010 feet. (*a*) 15 feet 6 inches, (*b*) 22 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No; there is but very little sea weeds of any kind near the outfall, the bed of the channel being entirely of sand. No green sea weeds are washed ashore.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	———— G. H. CARRINGTON Medical Officer of Health. Poole Borough and Port Sanitary Authority.

PORTMADOC, TREMADOC AND BORTHYGEST.

Question.	Answer.
1. Population of drainage area?	Portmadoc 3,487, Tremadoc 500, Borth 450.
2. Approximate volume of sewage discharged per diem?	Portmadoc 104,610 gallons, Tremadoc 15,000 gallons, Borth 13,500 gallons.
3. Nature of sewage and trade effluents (if any)?	Ordinary.
A typical analysis should be given, if possible.	Report of Analyst.

——	Portmadoc sewage.	Tremadoc sewage.	Borth sewage.
	No fœcal odour.	No fœcal odour.	No fœcal odour.
Saline and free Ammonia.	0·45	0.03	0·375 per 100,000
Albuminoid Ammonia	0·175	0·8	0 225 per 100,000
Oxygen absorbed in 2 hours at 80° F.	2·441	3.5	4 per 100,000
Nitrogen as Nitrates and Nitrites.	Slight traces.	Traces.	Very slight traces.
Total solids.	Not estimated. Practical nil in bottle.	Not estimated. Practically nil in bottle.	Not estimated. Practically nil in bottle.
Bacteriology.			
(*a*) No. of organisms	1,100,000 per c.c.	800,000 per c.c.	1,300,000 per c.c.
(*b*) Enteritidis sporogenes	200 per c.c.	100 per c.c.	100 per c.c.
(*c*) Coli	50,000 per c.c. in 48 hours.	20,000 per c.c. in 48 hours.	100,000 per c.c. in 48 hours.

Typhoid and Cholera organisms not looked for.

(Signed) F. N. Menzies, M.D.,
Public Health Laboratory,
King's College.

Question.	Answer.
4. Is the sewage discharged in the crude state?	Yes, at Portmadoc and Borth. At Tremadoc the sewage is passed into settling tanks two in number.
5. If not, to what process of treatment is it first subjected?	At Tremadoc the sewage settles in two tanks.
A typical analysis of the treated sewage should be given, if possible.	An analysis of the sewage effluent is given on the first page. The analyst says, "The Tremadoc sewage is a wonderful specimen—quite the purest I have ever examined."
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes, at all outlets except Tremadoc. That from Tremadoc cannot flow out owing to the lock gates being closed when the tide is fairly high. Portmadoc and Tremadoc are partly under high-water mark.
7. If not, during what period and at what state of the tide does the discharge take place?	Tremadoc sewage is discharged immediately the lock gates open, after the tide has ebbed for some time.
8. Are the tides sluggish or rapid near the point of outfall and what is their direction?	At Tremadoc and one of the Portmadoc outfalls the tides are rather sluggish. At Borth and the other Portmadoc outfall the tides are rapid. The tide ebbs towards open sea, and in rising flows up estuary of river.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Tremadoc sewage is discharged into a narrow tidal stream or "cut." No. 1 outlet Portmadoc also discharges into this tidal stream. No. 2 outlet Portmadoc discharges into the shipping harbour. Borth outfall is situated 264 yards from the shore. The depth of water at low spring tide is 12 inches, and at high spring tide 19 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.

PORTMADOC, TREMADOC AND BORTHYGEST—*continued.*

QUESTION.	ANSWER.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——
	P. FRASER, M.D. Medical Officer of Health. Carnarvon.

PORTSMOUTH.

QUESTION.	ANSWER.
1. Population of drainage area?	196,000.
2. Approximate volume of sewage discharged per diem?	Nominal flow about 8,000,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Sewage from dwelling-houses; trade effluent from breweries only.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state?	——
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	One hour after high water and then discharges for one hour.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Very rapid; during the time of discharge the tide flows to the south-east or direct into the English Channel.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide.	(*a*) About 20 feet. (*b*) About 34 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No growths whatever.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	None.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	The sewage of Portsmouth is carried by gravitation to a Pumping Station at Eastney and pumped through a 42-inch rising main into storage tanks of 4½ million gallons capacity, and from thence discharged into Langstone Channel one hour after high water. The current in the channel is from five to seven knots per hour, and the sewage is taken by the ebb-tide to the south-east into the English Channel. PHILIP MURCH, Borough Engineer.

PRESTON (LANCS).

Question	Answer
1. Population of drainage area?	115,505.
2. Approximate volume of sewage discharged per diem?	4¾ million gallons
3. Nature of sewage and trade effluent (if any)?	Domestic.
A typical analysis should be given, if possible?	——
4. Is the sewage discharged in the crude state?	No.
5. If not, to what process of treatment is it first subjected?	Sent through small straining tanks, afterwards used for broad irrigation of land.
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	On receding tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid.
9. At what distance from the shore is the outfall situated and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	33-inch pipes discharge through river wall into tidal river, about 2 feet above low water of spring tides.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Sludge, intercepted by straining tanks, is conveyed on to farm of 600 acres, and then worked into land. No formation of sludge in river.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	—
	H. O. Pilkington, Medical Officer of Health.

PWLLHELI.

QUESTION.	ANSWER.
1. Population of drainage area?	3,735.
2. Approximate volume of sewage discharged per diem?	59,760 gallons.
3. Nature of sewage and trade effluents (if any)?	Domestic.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No.
7. If not, during what period and at what state of the tide does the discharge take place?	Four hours per tide, at low tide, and the period before and after.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid Ebbing tide to south. Flowing tide to north.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low spring tide and (*b*) at high (spring) tide?	Close to shore. (*a*) 2 feet, (*b*) 12 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any other information of a similar nature which you may think useful.	———

T. CUNNINGHAM,
Surveyor

Per Dr. Fraser.

RAMSGATE.

QUESTION.	ANSWER.
1. Population of drainage area?	28,459.
2. Approximate volume of sewage discharged per diem?	About 1,100,000 gallons per twenty-four hours.
3. Nature of sewage and trade effluents (if any)?	Ordinary domestic sewage. There is no trade effluent beyond that from two small breweries and seventeen slaughter houses. The character of the effluent is very mild.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	It is discharged during twenty-one to twenty-two hours out of the twenty four.
7. If not, during what period and at what state of the tide does the discharge take place?	The tidal outfall sewer is tide-locked for about one to one and a half hours at high water. The outfall sewer is of 42 in. iron pipes, and it discharges just below the lowest low-water mark. The main intercepting sewers on the land are 6 ft. 0 in. by 4 ft. 6 in. brick sewers or 3 ft. 6 in. concrete tubes, with a good inclination to the outfall sewer.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	About four miles an hour. The flood tide flows for five hours in a westerly direction, and carries the sewage towards the south foreland. The ebb tide then flows for seven hours in a south-easterly direction, and carries it into the Gulf Stream and the neighbourhood of the Goodwin Sands.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	1,200 ft. (*a*) 4 ft. (*b*) 17 ft.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Never the slightest.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	The chief weed that grows on the chalk rocks is the common bladder wrack; it is no more abundant here than at all other parts of the sea coasts in Thanet. No nuisance arises from t.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	None whatever.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No. On the contrary, the neighbourhood of the outfall, within half a mile on either side, is a favourite spot for anglers from small boats.
14. Please furnish any further information of a similar nature which you may think useful.	——— T. G. STYAN, Ramsgate. Medical Officer of Health.

CITY OF ROCHESTER.

Question.	Answer.
1. Population of drainage area?	30,590 (Census 1901).
2. Approximate volume of sewage discharged per diem?	Impossible to say.
3. Nature of sewage and trade effluents (if any)? A typical analysis should be given, if possible.	Sewage crude. Trade effluents are small in quantity, and are from breweries and an oilseed mill. Several outlets are into open creeks, and there are many smaller outlets. Some of the outlets carry surface water alone, and the others water from surface drains into which house drains in some cases discharge.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Sluggish near outlets. Direction at right angles to outlet.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outfalls, with one exception, empty through rills running through the mud banks.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Nuisances frequently arise from the accumulation of sewage-polluted mud in the creeks and rills.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No weeds.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No actual banks of sludge are formed, but the mud of the creeks and rills is much sewage-polluted.

CITY OF ROCHESTER.—*continued.*

QUESTION.	ANSWER
13. Have any complaints been made as regards the effect of the discharge on fish life?	Yes. From oyster fisheries lower down the river. From local eel fisheries. From local shell-fish dealers generally. There is reason to suppose that cases of enteric fever have arisen through the consumption of uncooked shell fish gathered from various unauthorised localities in the river.
14. Please furnish any further information of a similar nature which you may think useful.	It should be stated that the present house drainage of Rochester is mainly into cesspools, which are pumped out or otherwise cleared and the contents put upon agricultural land. There is, undoubtedly, a certain quantity of crude sewage which finds its way into the river through the drains, but this represents a very small proportion of the total sewage of the city. Chatham and the other towns on the river are practically in the same position with regard to sewage disposal, although Gillingham has recently adopted main drainage and disposes of its sewage by chemical precipitation. The principal sources of the river pollution are, I should say, from the Government naval and military establishments abutting on the river. SIDNEY PRITCHETT, 18th March, 1904. Medical Officer of Health.

SCARBOROUGH.

Question.	Answer.
1. Population of drainage area?	Approximately 39,700 (middle of 1904). To this visitors must be added in summer months.
2. Approximate volume of sewage discharged per diem?	Approximately about ¾ million gallons per diem + rainfall
3. Nature of sewage and trade effluents (if any)?	Domestic only.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The rapidity varies with the state of the tide. Speaking generally, the flow is from the south out of the bay, and the ebb is towards the north. Thus nothing is deposited on either foreshore.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	There are two outfalls discharging at low water mark of ordinary tides, one situated at the point of junction of the harbour and the new marine drive, and the other outfall being situated at Scalby Ness.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No nuisance has to my knowledge ever arisen on the foreshore. With regard to the outfall near the harbour there is no nuisance, and has been none to my knowledge. With regard to the outfall at Scalby Ness, there is certainly nuisance, but as no one ever goes there, it does not cause any inconvenience.
11. Is there any considerable growth of green sea weeds such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	With regard to the outfall near the foreshore, I have noticed none. With regard to the outfall at Scalby Ness there is a considerable amount of green sea weed, and also much of the large, broad, brown sea weed. I have never heard of nuisance arising from decomposing sea weed washed ashore nor have I myself observed it.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	With regard to the outfall near the harbour, there is no evidence of the formation of sludge banks. With regard to the outfall at Scalby Ness, there is, near the outfall, what I take to be a sludge bank. Partly, however, this is composed of clay washed down from the cliff, which at this part is composed wholly of clay.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——

FRED DITTMAR, M.D.,
Medical Officer of Health.

NEW SHOREHAM, SUSSEX.

QUESTION.	ANSWER.
1. Population of drainage area?	3,837.
2. Approximate volume of sewage discharged per diem?	125,000 gallons.
3. Nature of sewage and trade effluents (if any)?	No trade effluent; ordinary house sewage.
A typical analysis should be given, if possible.	————
4. Is the sewage discharged in the crude state?	Occasionally when the filters are blocked.
5. If not, to what process of treatment is it first subjected?	Passed through two filters having 75 $\frac{5}{8}$ in. holes and 95 $\frac{3}{8}$ holes through the same respectively, and formed with parallel iron plates fixed 3 in. apart, the space thus formed being filled with coke. Precipitation of sludge takes place in front of filters, and is raised with buckets, mixed with road grit, and disposed of to a local farmer.
A typical analysis of the treated sewage should be given, if possible.	ANALYSIS. Grains per Gallon. Chlorine - 31·5 Nitrogen as Nitrates or Nitrites - a trace Free Ammonia - 5·25 Albuminoid Ammonia - 2·8 Oxygen consumed at 100° - 18·48 Oxygen after incubation at blood heat - 7·0 Sulphuric Acid as Sulphates - 1·99 Total solids - 137·2 Loss on ignition - 50·5
6. Is the sewage or treated effluent discharged at all states of the tide?	Only when the head of sewage is greater than the water in the river—as after heavy rain.
7. If not, during what period and at what state of the tide does the discharge take place?	On the ebb tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Sluggish at first, then more rapid.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	(*a*) 4 ft. from shore 1 ft. deep. (*b*) 90 ft. from shore 12 ft. deep.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No complaint has been received.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	There is growth (not considerable) of sea weed near the mouth of the river. Along the coast west of the river it grows in considerable quantities, and is at certain times washed into the river and causes a nuisance if disturbed during its decomposition.

NEW SHOREHAM, SUSSEX—*continued.*

QUESTION.	ANSWER
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	————
	9th July, 1904. C. M. KEMPE.

SOUTHAMPTON.

Question.	Answer.
1. Population of drainage area?	112,500.
2. Approximate volume of sewage discharged per diem?	3,000,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Chiefly domestic. Several breweries and one or two small dyers discharge into sewers.
A typical analysis should be given, if possible.	Analysis of Sewage. Free Ammonia - 5·0368 Albuminoid Ammonia - 0·9662 Solids in solution - 233·66 „ „ suspension - 35·36 „ total - 269·03 „ volatile - 78·29 Oxygen absorbed in four hours - 5·6357 The above are the averages of fourteen samples of sewage representing day and night flow.
4. Is the sewage discharged in the crude state?	At times a small amount is discharged in a crude state.
5. If not, to what process of treatment is it first subjected?	Partial subsidence.
A typical analysis of the treated sewage should be given, if possible.	Analysis of Effluent. Free Ammonia - 3·76 Albuminoid Ammonia - ·5957 Solids in solution - 175·871 „ suspension - 28·578 „ total - 204·449 „ volatile - 66·428 Oxygen absorbed in four hours - 4·8293
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	The main bulk of sewage is discharged on the ebb tide
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The tides are rapid on the ebb, which takes three hours to run away, owing to double tide.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The town is built to shore, and the tanks are situated on shore, to which the tide rises.

SOUTHAMPTON—*continued.*

QUESTION.	ANSWER.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	A considerable amount of mud-land surrounds the town, and in warm weather many persons object to the smell.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	There is a large amount of *ulva latissima* on the south and west sides of the town, where comparatively no sewage is discharged. The River Itchen, which receives the sewage of Southampton, Eastleigh, North Stoneham and Itchen Urban, although having considerable mud-banks, grows very little.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	There has been, but the sludge banks have been dredged.
13. Have any complaints been made as regards the effects of the discharge on fish life?	I am not aware of any. Salmon frequent both the Itchen and Test during the season.
14. Please furnish any further information of a similar nature which you may think useful.	——— R. E. LAUDER, Medical Officer of Health.

SOUTHEND-ON-SEA.

Question.	Answer.
1. Population of drainage area ?	38,000 (increasing).
2. Approximate volume of sewage discharged per diem ?	————
3. Nature of sewage and trade effluents (if any) ?	Effluents from gas works (to be stopped). Otherwise ordinary domestic sewage.
A typical analysis should be given, if possible.	————
4. Is the sewage discharged in the crude state ?	Yes.
5. If not, to what process of treatment is it first subjected ?	————
A typical analysis of the treated sewage should be given, if possible.	————
6. Is the sewage or treated effluent discharged at all states of the tide ?	No.
7. If not, during what period and at what state of the tide does the discharge take place ?	Sewage is discharged one hour after high water until one hour before low water.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Rapid. East and west.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide ?	Over a mile. (*a*) Top of pipe just visible. (*b*) 16 feet cover.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	Some along the coast, which sometimes washed ashore at the Southchurch beach and occasionally gave rise to a nuisance. Much less than formerly.
12 Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No.

SOUTHEND-ON-SEA—*continued.*

QUESTION.	ANSWER.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	Owing to the rapid ebb tide, and the discharge of the sewage over a mile from the shore only during the ebb-tide, the sewage from Southend is immediately diluted to an enormous extent and carried away miles seawards. The estuary is from six to seven miles broad at Southend and quickly widens. Occasionally when a strong south-east wind is blowing a scum may be seen on the water and a slight odour perceived at the head of the pier only, which is 1⅓rd miles from the shore, and about a quarter of a mile from the outfall. Apart from this I have never seen any evidence of sewage along the foreshore or along the whole length of the pier (with the exception of the pier head just mentioned). As the pierhead is, of course, in deep water at all states of the tide. the matter is more one of æsthetic than of sanitary interest.

J. T. C. NASH,

Medical Officer of Health.

SOUTHPORT (LANCASHIRE).

QUESTION.	ANSWER.
1. Population of drainage area?	49,600 (estimated to middle of 1904).
2. Approximate volume of sewage discharged per diem?	1,500,000 gallons. Including subsoil water, about 2,000,000 per diem.
3. Nature of sewage and trade effluents (if any)?	A weak domestic sewage. Trade effluents from brewery, &c., practically a negligible quantity.
A typical analysis should be given, if possible.	IN GRAINS PER GALLON.

Samples.	Smell.	Chlorides.	Suspended Matter.	Oxygen absorbed by Pot. Permag. in 4 hrs. at 80 °F	Nitrates and Nitrites
Crude sewage taken 6 a.m. June 13, 1900	Sewage	14·6	5·0	2·3	None
Crude sewage taken 6 p.m. June 21, 1900	Strong sewage	22·4	13·1	4·0	None
Crude sewage taken 6 p.m. July 17, 1900	Strong sewage	14·1	16 8	6·30	None

The last two samples taken later in day will be noticed to be stronger than the first taken in early morning. These are the latest analyses we have.

QUESTION.	ANSWER.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	A very small quantity of sewage is intermittently treated on two small experimental bacterial beds, but the bulk of the sewage is untreated.
A typical analysis of the treated sewage should be given, if possible.	——

THE FOLLOWING ANALYSES simply show the results obtained by our small experimental coke-filter beds soon after they were put down, and as far as they went, were considered very satisfactory. The samples of *crude* sewage are the same as the two last of those given under Question 3.

—	Smell.	Chlorides.	Suspended Matter.	Oxygen absorbed in in 4 hrs. at 80° F.	Percentage of purification.	Condition after standing 72 hrs. in bottle at room temperature.	Nitrates and Nitrites.
Samples taken June 21, 1900.			In	Grains per G	allon.		
Crude sewage - - - - -	Strong sewage	22·4	13·1	4·0	0	Decomposed and gone black	None
Effluent of same, after treatment on first filter bed (for 2 hrs.)	Distinct sewage	24·0	2·7	1·5	62·5	Not decomposed	None
Final effluent, after treatment for 2 hrs. each, on first and second filter bed.	Faint sewage	49·0	0·4	0·5	87.5	Not decomposed	0·5
Samples taken July 17, 1900.							
Crude Sewage - - - - -	Strong sewage	14·1	16·8	6·30	0	Black and smell of H_2S	None
Effluent from coarse bed (first bed)	Sewage	16·4	4·1	2·66	58	Ditto	None
Effluent from fine bed (second bed)	Nil	21·8	0·8	1·05	83	Clear and no smell	1·0

The increase and amount of chlorides in the effluents as compared with the amount in the crude sewage is probably due to salt spray from the sea passing over the beds

SOUTHPORT (LANCASHIRE)—*continued.*

QUESTION.	ANSWER.
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	————
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Sluggish—directly towards the land. Near the sewer outlet is a small land-water channel (into which the sewer outlet is discharged), up which some sewage is carried for about a quarter of a mile from the sewer outlet, as the tide comes in.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Outfall discharges into tidal channel on shore, about a quarter of a mile away from any habitation, and about three miles away from Southport. (*a*) Just out of water. (*b*) 8 ft. deep.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Complaints have been made for many years by inhabitants of Crosseus, a fishing village about a quarter of a mile from sewer outlet, but (as mentioned under Question 12) it has always been a question whether or how much of the nuisance has been caused by deposit of sewage, or by deposit of débris, &c., from slow running waters from peaty agricultural land.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	There are some sludge banks close to sewer outlet and along channel mentioned in Question 8, but it has always been a question locally as to how far they are caused by sewage or by débris, &c., deposited from the land waters coming down said channel.
13. Have any complaints been made as regards the effects of the discharge on fish life?	Not to my knowledge.
14. Please furnish any further information of a similar nature which you may think useful.	I am of opinion that all places discharging crude sewage into the sea ought to be called upon to adopt *some* system of treatment.

JOHN J. WEAVER,

Medical Officer of Health.

SOUTH SHIELDS.

Question.	Answer.
1. Population of drainage area?	107,000.
2. Approximate volume of sewage discharged per diem?	1,500,000 gallons.
3. Nature of sewage and trade effluents (if any)?	The great proportion of the houses are provided with ash closets, there being only about 5,000 water-closets in the town. There are no trades carried on in the borough the effluent from which is of any importance, except possibly the gas works. There are, however, large deposits of alkali waste (the relics of former extensive chemical industry), and soakage from these finds its way into certain of the sewers; this soakage is charged with various sulphur compounds, and gives off H_2S (sulphuretted hydrogen) in varying amount.
A typical analysis should be given if possible.	None available.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	No; all the sewers are tide-locked.
7. If not, during what period and at what state of the tide does the discharge take place?	The sewers are locked for two hours before and two hours after high tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Moderately swift; mostly at right angle to the mouths of the sewers. None of the sewers debouch on the coast line, but all enter the River Tyne.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	There are 14 outfalls, all at a level midway between low and high water with the exception of two, which discharge 3 feet below low-water mark.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Yes. We have had complaints almost solely with regard to one outfall. This outfall is peculiarly situated. Immediately below it, *i.e.*, lower down the river, is the ferry landing-stage, and below this again is a small natural creek, the "Mill Dam." The complaint has been two-fold—(*a*) of offensive smells from the mouth of the sewer, and (*b*) of deposit of black offensive material in the creek and foul odours proceeding therefrom. As far as I could personally ascertain, the odour was almost purely that of H_2S, from the sewer mouth, and of H_2S plus a slight trace of ordinary sewage smell from the deposit in the creek. This nuisance has been very greatly mitigated within the last year by dredging the creek so as to provide for the constant presence of water therein, and by placing a hood over the sewer so that the mouth is not exposed at any time of the tide.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Vide reply to 9 and 10. There is evidence of deposit in the vicinity of the sewer there referred to, outside as well as in the creek.

South Shields—*continued*.

Question.	Answer.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——

JOHN J. BOYD.

STIRLING.

QUESTION.	ANSWER.
1. Population of drainage area?	18,800.
2. Approximate volume of sewage discharged per diem?	1,050,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Principally house sewage. No obnoxious trade effluents.
A typical analysis should be given, if possible.	——
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid seawards, the river having a good flow in addition to outgoing tide.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Discharge direct into river. (*a*) Five to six feet. (*b*) Thirteen to fourteen feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Yes, when the main outfall discharged into a creek short of the river, but that was rectified in 1899 by carrying the sewer forward to the river and filling up the creek. There is no nuisance whatever now.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——

A. FAIRLIE WILSON,
Medical Officer of Health.

February 26th, 1904.

STOCKTON-ON-TEES.

QUESTION.	ANSWER.
1. Population of drainage area?	53,000.
2. Approximate volume of sewage discharged per diem?	1,000,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Surface water, domestic drainage. Sewage from about 2,500 water closets. " " a brewery - - about 1,100 gallons daily. " " slaughter-houses - " 1,000 " " " " tripe boiling - - " 10,000 " " " " bacon curing - - " 3,000 " " " " laundry - - " 12,000 " " " " confectionery works " 1,000 " "
A typical analysis should be given, if possible.	No analysis available.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outlets, five in number, are on the bank of the River Tees, about eleven miles from the mouth. Two of them discharge below low water level and three at the mean level of spring tide.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	Objectionable odours have been observed occasionally.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	Doubtless the mud which is constantly being deposited on the banks of the river contains a certain proportion of solid material derived from sewage, but to the ordinary observer this cannot be differentiated from ordinary alluvium.
13. Have any complaints been made as regards the effect of the discharge on fish life?	I have not heard of any.
14. Please furnish any further information of a similar nature which you may think useful.	———

THOMAS HORNE.

SUNDERLAND.

QUESTION.	ANSWER.
1. Population of drainage area?	About 150,000.
2. Approximate volume of sewage discharged per diem?	Have no records.
3. Nature of sewage and trade effluents (if any)?	Brewery effluents, laundry effluents.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Fairly rapid.
9. At what distance from the shore is the outfall situated and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	There are sixteen outlets altogether, some discharging into the sea direct and the remainder into the river Wear which is a tidal river. The farthest outlet from the sea is situated about 1½ miles up the river.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	None.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Sea weed is washed ashore occasionally in heavy weather and causes a nuisance when decomposing.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	None.
13. Have any complaints been made as regards the effects of the discharge on fish life?	None.
14. Please furnish any further information of a similar nature which you may think useful.	———
	HENRY RAMEY, Medical Officer of Health.

SWANSEA.

QUESTION.	ANSWER.
1. Population of drainage area?	Swansea County Borough, 96,624, estimated (1903).
2. Approximate volume of sewage discharged per diem?	Dry weather, 5 million gallons approximately.
3. Nature of sewage and trade effluents (if any)?	Effluent of many important metal industries, including iron, steel, tinplate, silver, lead, copper, nickel and chemical works—within the County Borough of Swansea, not including metal works higher up the Swansea Valley, but not within the boundaries of the County Borough.
A typical analysis should be given, if possible.	No analysis has been made of the sewage and trade effluents.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	——
A typical analysis of the treated sewage should be given, if possible.	——
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	——
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid, during flow and ebb of the tide. Range of tide level from high to low water; ordinary spring tides 29 feet.—(Borough Engineer). Flood tide, eastwards; ebb tide, westwards, opposite the mouth of the Swansea river (Tawe).
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Main outfall delivered through quay wall into river within a few inches above level of Ordnance datum. (*a*) 12 feet at high water, low spring tide; (*b*) 16 feet at high water, high spring tide.—(Borough Engineer).
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	A few complaints have been received
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	There is some growth of the sea weed described, but not considerable along the shore of Swansea Bay. No nuisance arising from this cause has been brought under my notice.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	It is alleged that there is a gradual accumulation opposite the Swansea main outlet sewer, which accumulation is removed in the course of ordinary dredging of the river channel, towards the removal of which a contribution is made to the Swansea Harbour Trust by the Urban Sanitary Authority.—(Borough Engineer).
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——

E. DAVIES,
Medical Officer of Health.

March 3rd, 1904.

TEIGNMOUTH, DEVON.

QUESTION.	ANSWER.
1. Population of drainage area ?	Census, 1901, 8,502 ; estimate, 1903, 8,540.
2. Approximate volume of sewage discharged per diem ?	Average daily water supply, 1903, 178,250 gallons.
3. Nature of sewage and trade effluents (if any) ?	Ordinary domestic sewage. No trade effluents.
A typical analysis should be given, if possible.	No analysis available.
4. Is the sewage discharged in the crude state ?	Yes, from three outfalls in Teignmouth and three in Shaldon.
5. If not, to what process of treatment is it first subjected ?	—
A typical analysis of the treated sewage should be given if possible.	—
6. Is the sewage or treated effluent discharged at all states of the tide ?	Yes, with the exception of the 30-inch main Teignmouth outfall, which is the largest and most important.
7. If not, during what period and at what state of the tide does the discharge take place ?	The 30-inch main Teignmouth outfall discharges only on the ebb, beginning one hour after high water and ceasing an hour and a half before low water.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction ?	Rapid. Generally at right angles to the line of sewer.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide, and (*b*) at high (spring) tide ?	

—	Below high water mark.	Below low water mark.
	Feet.	Feet.
30-inch main, Teignmouth - -	205	9
Coombe, „ - - -	315	4–5
Forester's Lane, „ - - -	?	„
Eleff's Quay, Shaldon - - -	155	„
Main Sewer, „ - - - -	590	„
Ringmore „ „ - - - -	530	„

(*b*)

—	Depth at high springs.
	ft. in.
30-inch main, Teignmouth - - - - -	7 6
Coombe, „ - - - - -	4
Forester's Lane, „ - - - - -	—
Eleff's Quay, Shaldon - - - - -	5 8
Main Sewer, „ - - - - - -	7 4
Ringmore „ „ - - -	5 6

The range of spring tides is 13 feet; allowance for wind variation about 1 foot 6 inches either way.

TEIGNMOUTH, DEVON.—*continued.*

QUESTION.	ANSWER.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore ?	Yes ; complaints are common in summer as to floating solids deposits on foreshore, and smell.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing ?	*Ulva latissima* is plentiful, floats to and fro with the tide, and is often deposited, in decomposing state, upon the large sand bank in centre of harbour, known as "Salty." In late summer of 1895 an enormous quantity (250–300 tons) was washed into a hollow in the bar at mouth of river, and there lay decomposing for weeks; it caused great nuisance till buried *in situ* by Sanitary Authority. I have not identified *enteromorpha.*
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	No.
13. Have any complaints been made as regards the effect of the discharge on fish life ?	Generally; from Devon Sea Fisheries Committee, and from Teign Board of Conservators; also, as to effect on shellfish layings, but all the local outfalls are well on the seaward side of the shellfish beds, over which however, the untreated sewage from the town of Newton Abbot and from a number of riparian villages flows in its passage towards the sea. There are important mussel beds in the river above Teignmouth, the molluscs being laid there to fatten, and ultimately finding their way into the London and Midland markets. I have seen these, prior to removal by train, lying in bags in the river close to the main sewer outfall. Locally, there is no undue prevalence of enteric fever, but scattered cases have been from time to time undoubtedly caused by mussels and cockles from the Teign, as reported by me so long ago as 1893. There are no oyster beds.
14. Please furnish any further information of a similar nature which you may think useful.	———

T. CECIL H. PIGGOTT, M.D.,
Medical Officer of Health.

BOROUGH OF TORQUAY.

Question.	Answer.
1. Population of drainage area?	Estimated for 1903, 33,800.
2. Approximate volume of sewage discharged per diem?	Dry weather flow about 1,180,000 gallons per diem.
3. Nature of sewage and trade effluents (if any)?	Ordinary domestic sewage. Surface water is also removed by sewers.
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tides?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Rapid. South east.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The invert at the outfall is only 3 feet below mean high water mark, and the crown of the sewer four feet above. The sewer will therefore discharge at high water of the highest tides.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	None. There are no houses near the outfall.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	There is a certain amount of growth of green sea weeds on the rocks near, but no complaint of smell arising from its decomposition has been made.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids.	None.
13. Have any complaints been made as regards the effects of the discharge on fish life?	None. I understand that near the outfall is a favourite place for fishing.
14. Please urnish any further information of a similar nature which you may think useful.	———
	T. Dunlop M.B., Medical Officer of Health.

TYNEMOUTH.

Question.	Answer.
1. Population of drainage area?	53,000.
2. Approximate volume of sewage discharged per diem?	1,060,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Have no information.
A typical analysis should be given, if possible.	Have no analysis. The chief industry is ship-building, with its allied trades. There are also lead works, sewage from which discharges into one of the docks—the Northumberland Dock, and close to the mouth of the River Tyne, a flourishing fishing trade. Dependent upon the latter are numerous curing houses, and a fish refuse manufactory. Outfall sewer from these is at Fish Quay. See answer to question 12.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	Yes.
7. If not, during what period and at what state of the tide does the discharge take place?	———
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	In no case are the tides sluggish, but their speed varies with varying conditions of weather. In some cases the set of the tide is at right angles to the line of the sewer, in others the set of the tide and the line of the sewer are the same.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	With one or two exceptions the outfalls are situated at low water level extraordinary spring tide. High springs are about 18 ft. above low spring level.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No complaints have been received.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Yes. *Ulva latissima* and *enteromorpha* grow plentifully near to, and away from, the outfalls along the coast, and within the piers up to the Fish Quay. *Enteromorpha* also grows higher up the river. Had no complaint.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	A slight bank is formed at one outfall, and the various outfalls have to be cleared at intervals of the accumulations which gather about them.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
4. Please furnish any further information of a similar nature which you may think useful.	———

J. Edward Gofton,
Medical Officer of Health.

WEYMOUTH AND MELCOMBE REGIS.

QUESTION.	ANSWER.
1. Population of drainage area?	At Census of 1901 it was 19,843. Now estimated to be 20,450.
2. Approximate volume of sewage discharged per diem?	About 400,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Purely domestic from the town outfall sewer. Refuse from two large breweries is discharged separately into harbour.
A typical analysis should be given, if possible.	No analysis obtainable.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	No, except during heavy rainfall, when an exceptional amount of storm water has to be dealt with at the pumping station.
7 If not, during what period and at what state of the tide does the discharge take place?	During the ebb of the tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The tides are sluggish—1½ to 2 knots an hour. Their direction is away from the town, from N. to S. and from N.E. to S.E.
9. At what distance from the shore is the outfall situated and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	The outfall is situated some 1,200 feet from the nearest point of the shore and that is a promontory. Depth (*a*) at low spring tide, 25 feet. „ (*b*) at high „ „ 31 „
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No nuisance has arisen to my knowledge since the outfall sewer was prolonged to its present distance from the shore about three years ago. Occasionally it is said that a smell is perceptible at the outfall when pumping first begins, probably due to the escape of imprisoned gases. Formerly the outfall was only 200 feet distant from the shore, and then it did give rise to nuisance.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful.	——— T. HENRY JONES, M.D., Medical Officer of Health.

WORTHING.

QUESTION.	ANSWER.
1. Population of drainage area?	About 24,000.
2. Approximate volume of sewage discharged per diem?	800,000 gallons.
3. Nature of sewage and trade effluents (if any)?	Of ordinary domestic character. No trade effluents,
A typical analysis should be given, if possible.	———
4. Is the sewage discharged in the crude state?	———
5. If not, to what process of treatment is it first subjected?	Sewage passes through screens, and is then lifted into high level tanks.
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	———
7. If not, during what period and at what state of the tide does the discharge take place?	One hour after high water.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	Tides are rapid and have a south-westerly direction.
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	1,200 feet south of high water mark ; (*a*) about one foot ; (*b*) about seventeen feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	No.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	No.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids?	No.
13. Have any complaints been made as regards the effects of the discharge on fish life?	No.
14. Please furnish any further information of a similar nature which you may think useful?	———

CHAS. KELLY, M.D.,
Medical Officer of Health.

GREAT YARMOUTH.

QUESTION.	ANSWER.
1. Population of drainage area?	52,092.
2. Approximate volume of sewage discharged per diem?	One million gallons.
3. Nature of sewage and trade effluents (if any)?	A considerable proportion of the houses in the town are fitted with water closets. Very little trade effluent of any kind.
A typical analysis should be given, if possible.	No typical analysis of the sewage is available, but the results of a recent analysis of the water of the River Yare are given below:—
	Total solid matter (grs. per gallon) - 1608·0 Chlorides (as Chloride of Sodium) - 1417·28 Nitrates - trace. Ammonia (Free) - ·0273 „ (Albuminoid) - ·0140 Oxygen absorbed in 15 minutes at 140° F. - ·3360
	This analysis concerns a sample which was drawn from the Yare at the time of ebb tide at a point below the main sewage outfalls.
4. Is the sewage discharged in the crude state?	Yes.
5. If not, to what process of treatment is it first subjected?	———
A typical analysis of the treated sewage should be given, if possible.	———
6. Is the sewage or treated effluent discharged at all states of the tide?	More than three quarters is discharged on the ebb.
7. If not, during what period and at what state of the tide does the discharge take place?	Generally at half ebb tide.
8. Are the tides sluggish or rapid near the point of outfall, and what is their direction?	The tide in the Yare usually runs at an average of three miles an hour at the time of half ebb, but is frequently faster (up to 5½ miles an hour).
9. At what distance from the shore is the outfall situated, and in what depth of water (*a*) at low (spring) tide and (*b*) at high (spring) tide?	Sewer outfalls in a strong tidal river, mostly placed so as to be covered at low tide. (*a*). Average 7 feet. (*b*). Average 11 feet.
10. Has any nuisance arisen at any time either in the neighbourhood of the outfall or on the foreshore?	The outfalls are 22 in number, and the immediate dilution is so great that no nuisance arises.
11. Is there any considerable growth of green sea weeds (such as *ulva latissima* or the different varieties of *enteromorpha*) near the outfall or along the coast, and, if so, does a nuisance ever arise in warm weather from the weeds being washed ashore and decomposing?	Practically no growth of any kind of seaweed.

GREAT YARMOUTH—*continued.*

QUESTION.	ANSWER.
12. Is there any evidence as to the formation of sludge banks in the neighbourhood of the outfall or elsewhere caused by deposit of sewage solids ?	None.
13. Have any complaints been made as regards the effects of the discharge on fish life ?	No complaints have been made as to the deleterious effects on fish life. There is reason to believe that mussels dredged from the Yare near the outfalls have produced typhoid fever in the past.
14. Please furnish any further information of a similar nature which you may think useful.	The Yare is a strong tidal river, and all the sewer outfalls are within $2\frac{3}{4}$ miles miles of its mouth. There is no expanse of mud exposed at low tide, so that there is no nuisance produced by the sewage which may be remaining at the end of the ebb tide. There is no return of sewage by the action of the flood tide. Floats have been put in at the sewage outfalls at the usual time of discharge offering rewards for the return of the enclosed cards, but up to the present no card has been returned.

W. H. BEACH,

Great Yarmouth. Medical Officer of Health.

APPENDIX.

SOME OBSERVATIONS ON THE EFFECTS OF THE DISCHARGE OF SEPTIC TANK SLUDGE INTO A TIDAL ESTUARY.

By Gilbert J. Fowler, D.Sc., F.I.C.

A number of observations have recently been made in connection with the discharge into tidal waters of sludge from a septic tank installation designed by the writer in conjunction with Mr. J. P. Wilkinson, M.I.C.E., for the Admiralty Training Station at Shotley, near Ipswich.

These observations were in part suggested by the Reports by Letts and Adeney on the pollution of estuaries and tidal waters which the author was privileged to read in proof form.

It was in the first place of interest to discover how far their suggested standards of dilution would apply to the conditions at Shotley, while in view of the work of Purvis and Coleman,* of Clark† and also of certain unpublished results of the author there appeared room for further investigation of the effects of sea-water and fresh-water respectively on the rate of change of suspended sewage matters.

Shotley is a land station for youths taken from the old training ships. It is situated opposite the town of Harwich on the south side of a small peninsula having the river Orwell on the north and the river Stour on the south. Shotley point is at the junction of the mouths of the two rivers.

The position of the septic tank installation and the outfall can be seen from the accompanying sketch map, on which also the track of the sludge discharge is indicated.

The sewage installation was designed for a population of 2,000 and consists of septic tanks followed by percolating filters, the effluent from which flows continuously out over the foreshore. Arrangements were made in the design for taking away the sludge in tank carts from time to time, but it was found more convenient to discharge it into the sea at suitable states of the tide.

About 8,000 gallons of mixed sludge and water were let out at each discharge, the operation extending over about half an hour.

The sludge valve was opened immediately upon or shortly after high tide, and the track of the discharged sludge observed. In all cases it passed along with the tidal water to the junction of the Stour and Orwell estuaries, where it apparently became indefinitely disseminated.

On October 2nd, 1906, samples were taken from a boat about 200 yards below the outfall in the track of the sludge. The time of high tide was 11.45 a.m., the sludge was let out from 12.0 noon to 12.30 p.m., and the samples were collected at 12.20 p.m. The samples were taken about one foot below the surface, care being exercised to prevent any air being mixed with the sample during collection. Two small bottles were filled for immediate examination, and a half Winchester was taken for detailed analysis on returning to Manchester.

The dissolved oxygen was determined in the small bottles by the Winkler method, in the one case shortly after collection, and in the other case six hours later.

On returning to Manchester a portion of the larger sample was carefully syphoned off and the dissolved oxygen determined. A portion of the remainder was re-aerated and incubated at 20° C. for twelve days, and another portion submitted to a routine analysis.

A similar procedure was followed with samples taken at 2.30 p.m., or about two hours later on the same day.

A sample of sea-water was also taken for comparative purposes at a point above the outfall.

The results are summarised in the following table :—

—	Sample A. 12.20 p.m. October 2nd, 1906.		Sample B. 2.30 p.m. October 2nd, 1906.	
	Parts per 100,000.	C.c. per Litre.	Parts per 100,000.	C.c. per Litre.
Dissolved Oxygen.				
Shortly after collection	0·649	4·54	0·847	5·93
6 hours „ „	0·667	4·67	0·811	5·68
10 a.m., October 4th	0·342	2·39	0·738	5·16
After re-aeration and incubation for 12 days at 26° C.	Nil and smell of H_2S.		0·342 (Sea-water incubated similarly = 0·522).	2·39 3·65
	Numbers in parts per 100,000.		Numbers in parts per 100,000.	
General Analysis, etc., October 4th.				
Colour	Nil.		Nil.	
Transparency	Opalescent with grey sediment.		Opalescent with whitish sediment.	
Smell	Very faint sewage.		Sea-weed.	
Oxygen absorbed 4 hours‡	0·54		0·24	
Ammoniacal Nitrogen	0·002		0·003	
Albuminoid „	0·092		0·027	
Nitrous „	Trace, more than B.		Trace.	
Chlorine	1930 (Sea-water 1940).		1910	

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* "The Influence of Sea-Water on the Decomposition of Sewage," *Journal, Royal Sanitary Institute*, 1906, p. 433.

† Report of Charles River Dam Committee, 1903. Boston, Wright and Potter Printing Company.

‡ At laboratory temperature.

Allowing for small manipulative and analytical errors the above results show clearly :—

1. That the sludge quickly becomes mixed with a large excess of sea-water.
2. That in the course of 6 hours, *i.e.*, by half tide, practically no absorption of dissolved oxygen takes place at such a dilution and consequently no nuisance can arise from the discharge of sludge under these conditions.
3. That two hours after discharge very little sludge can be detected in the water 200 yards from the outfall.

A similar set of samples were taken on May 29th, 1907. In this case the sludge was discharged from 1.30 p.m. to about 1.45 p.m., high tide being at 12.55 p.m. The intention was to discharge the sludge immediately at high tide, but a strong wind retarded the ebb for some time. One sample was taken about a quarter-mile from the outfall about 2.15 p.m., the other an hour later and rather further out. As before small and large samples were taken, but in this case, after determining the dissolved oxygen in one small sample immediately on returning to the shore, the other was securely fastened and sent back to Manchester and the dissolved oxygen determined some two days later, the samples not being incubated, in fact being kept for some hours after arrival in the refrigerator. They were at any rate kept during transit, &c., about 36 hours, at the ordinary temperature.

The following results were obtained :—

——	*Sample A.* 2.15 p.m. May 29th, 1907.		*Sample B.* 3.15 p.m. May 29th, 1907.	
	Parts per 100,000.	C.c. per litre.	Parts per 100,000.	C.c. per litre.
Dissolved Oxygen.				
Shortly after collection	0·705	4·93	0·83	5·81
May 31st	0·53	3·71	0·78	5·46
	Numbers in parts per 100,000.		Numbers in parts per 100,000.	
General Analysis, etc., May 31st.				
Colour	Nil.		Nil.	
Transparency	Clear with dark brownish sediment		Clear with light brown sediment.	
Smell	Nil.		Nil.	
Oxygen absorbed 4 hours*	0·34		0·105	
Ammoniacal Nitrogen	0·016		Nil.	
Albuminoid ,,	0·053		0·02	
Chlorine	1870		1880	

This set of observations agrees with the first in showing that in a short space of time the sludge becomes disseminated to such an extent as only very slightly to affect the composition of the water. The conditions at Shotley, it will thus be seen, fall easily within the standards either for Class I. or Class II. on p. 95 of Letts and Adeney's report.

It was thought of interest to make some attempt to follow the ultimate fate of the organic matter, some of which is presumably deposited over a considerable area of the sea bottom. At the same time comparative observations were made of the course of decomposition in sea-water and fresh-water respectively.

For this purpose samples of sludge were taken from the inlet and outlet manholes respectively of one of the septic tanks. These samples were passed through a ¼ mm. sieve to remove grit, fibrous matter, etc., and 10 cc. of the resultant mud added to a litre of sea-water and tap-water respectively. This solution was further diluted to half strength.

The following solutions were thus obtained, which were distinguished as S_1 S_2 etc. ;

$S_1 = 1$ per cent. by vol. inlet sludge and tap-water.
$S_2 = 0·5$,, ,, ,, ,, ,, ,,
$S_5 = 1·0$,, ,, ,, ,, sea- ,,
$S_6 = 0·5$,, ,, ,, ,, ,, ,,
$S_3 = 1·0$,, ,, outlet ,, tap- ,,
$S_4 = 0·5$,, ,, ,, ,, ,, ,,
$S_7 = 1·0$,, ,, ,, ,, sea- ,,
$S_8 = 0·5$,, ,, ,, ,, ,, ,,

500 cc. each of these mixtures were placed in half Winchester bottles plugged with cotton wool. The bottles being each of litre capacity were half full of air, and in addition to the free circulation of air through the cotton wool plugs, the aeration was increased by periodical shaking.

Before describing the changes taking place in these bottles the following analyses of the original sludges after sieving should be given :—

——	Inlet Sludge.	Outlet Sludge.
Percentage dry matter	9·3	9·0
Organic and volatile in dry matter	24·2	57·3
Mineral in dry matter	75·8	42·7
Ether Extract (per cent. on total)	5·6	7·0
Ether Extract (per cent. on organic and volatile)	23·1	12·2

Incidentally it may be mentioned that a good deal of grit, fibrous and fatty matter, etc., was left on the sieve in the case of the inlet sludge, while nearly all the outlet sludge passed through the sieve. The septic tank has thus the effect of breaking up the original solid organic matter in the sewage and consequently, as the sludge is only discharged from the outlet end or near the middle of the tank, it is in a condition to be rapidly disseminated throughout the water without the appearance of unsightly floating solids, and without the likelihood of rapid settlement of heavy solids.

The analytical figures show clearly that grit is deposited at the inlet end of the tank and also that the percentage of fatty matter extractible by ether diminishes in the course of tank treatment.

Very little smell was apparent from the first, in the mixtures of *inlet sludge*, either with tap-water or sea-water.

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* At laboratory temperature.

The following analyses, made on December 19th, 1906, after 76 days, of the 0·5 per cent. mixtures show that although ammoniacal fermentation had taken place in both cases, nitrification had been inhibited in the case of the mixture with sea-water.

——	S_2 (0·5 Inlet sludge and tap-water.)	S_6 (0·5 per cent. Inlet sludge and sea-water).
Ammoniacal Nitrogen	·025	·21
Albuminoid "	·115	·13
Nitrous and Nitric Nitrogen	·20	·02

In the case of the *outlet sludge* mixtures there was a greater proportion of organic matter and all the mixtures had an offensive smell to begin with. This disappeared in about a week in the case of both the tap-water mixtures and also in the case of the 0·5 per cent. sea-water mixture. The 1 per cent. mixture with sea-water was, however, black and putrid at the end of a month.

S_4 and S_8 were analysed on December 19th, *i.e.*, after two months exposure with the following results :—

——	S_4. (0·5 per cent. Outlet sludge and tap-water).	S_8. (0·5 per cent. Outlet sludge and sea-water).
Ammonical Nitrogen	·016	·082
Albuminoid "	·26	·26
Nitrous and Nitric Nitrogen	Trace.	Nil.

Here again the lesser proportion of free ammonia in the tap-water mixture is evidence that nitrification is inhibited by the sea-water.

The 1 per cent. samples show a curious sequence of changes. As before remarked, the sea-water mixture remained putrid long after the fresh-water mixture, and the results with the 0·5 per cent. mixtures show that oxidation of the ammonia to nitrites and nitrates proceeds more rapidly in fresh-water.

On prolonged keeping, however, it was noticed that a small amount of green growth took place in the fresh-water sample which was absent from the sea-water, and on determining the free ammonia in S_3 (tap-water) and S_7 (sea-water) on April 19th, 1907, or seven months from the beginning of the experiment, 0·60 of ammoniacal nitrogen was found to be present in S_3 and only 0·20 in S_7.

No nitrite or nitrate could be found in S_3 but abundant *nitrite* was present in S_7. It is possible, therefore, that the nitrates originally formed in S_3 had been consumed by the green growth, which afterwards had suffered decomposition, reproducing ammonia.

It is curious to note that the loss on ignition of the suspended solids after these were collected by centrifuge and washed by decantation was always greater in the case of the fresh-water mixtures.

This is shown in the following tables :—

Inlet Sample	Description.	Percentage loss on ignition of dry matter.
S_1	1 per cent. + tap-water.	56·0
S_5	1 " " + sea-water.	48·3
S_2	0·5 " " + tap-water.	58·4
S_6	0·5 " " + sea-water.	55·0

Outlet Samples.	Description.	Percentage loss on ignition of dry matter.
S_3	1 per cent. + tap-water.	53·5
S_7	1 " " + sea-water.	42·7
S_4	0·5 " " + tap-water.	58·6
S_8	0·5 " " + sea-water.	53·0

It was noticeable also that the suspended solids in the fresh-water mixtures had a more flocculent appearance than the corresponding sediment in the sea-water mixtures.

It seems, therefore, as if sea-water inhibits to some extent the growth of algae, etc., which develop by utilisation of the organic matter. There would thus appear to be actually less organic matter present after long exposure of mixtures of sludge and sea-water than after similar mixtures with tap-water are exposed. A comparison of losses on ignition after exposure with those of the original samples as given in an earlier table also shows that little or no actual loss of weight has occurred in either case. Too much stress should not, however, be laid on this point, as the quantities to be weighed were comparatively small.

No doubt under natural conditions some of the organic matter would be consumed by infusoria and other low forms of life and thus enter once more upon a cycle of change. The inorganic matters will, however, eventually deposit, carrying with them also some of the organic matters of a more resistant kind.

In order to discover whether any evidence of such a deposition was left upon the foreshore, a careful examination was made at low-tide on September 20th, 1907, extending from the effluent outlet about a quarter of a mile along the track of the sludge discharge, samples being taken at different points.

The foreshore consists mainly of thick grey mud, shallow patches of sand occurring at intervals. There was no evidence anywhere of any permanent deposit of sludge or sewage matter. Immediately below the surface of the clay there was a blackish sub-stratum. This was apparently due to organic matter normally present, as it was found in places quite outside the track of the sludge and began always just beyond the limit of depth to which the air could penetrate. Evidences were frequent of the presence of molluscs, etc., below the surface of the clay, and this was always blackest in their neighbourhood, no doubt because of sulphate reduction caused by their excretions. None of the samples had any very appreciable smell, even after incubation, and loss of ignition of a sample taken close to the outfall was only 5 per cent., while a sample taken much nearer the dry land and out of the track of the sludge gave a loss of 8 per cent., both samples being sieved through a ¼ mm. mesh.

Scattered ribbons of *ulva latissima* were frequently in evidence here and there on the foreshore. A workman who was present contended that the weed was washed down from Ipswich. At any rate there were certainly no banks of it in course of formation.

As a result of the foregoing investigations, therefore, it may be concluded, if sludge consisting of finely comminuted solids, such as accumulate at the exit end of a septic tank, is discharged at the top of the ebb-tide under the conditions obtaining at Shotley, that while a temporary discolouration and pollution of the water takes place in the track of the sludge, yet at no time is the aeration reduced appreciably between tides, and finally the solids are so widely distributed that no visible effect is produced, although the actual transformation of the organic matter requires considerable time.

The researches have further shown clearly that, under the conditions of experiment described, nitrification does not proceed so quickly in sea-water as in fresh, and both under these conditions, and under those described by Adeney,* oxidation of nitrogen only reaches the stage of *nitrite* formation, in presence of sea-water. It has also been shown that the smell is much more persistent in mixtures of sludge and sea-water than in similar mixtures with fresh water, and therefore special care is necessary, before discharging unoxidised sewage matter into the sea, to be sure that the conditions are such that nuisance cannot arise. In the present case other means of sludge disposal had been provided for, if the sea discharge had been found impracticable. Even as it was the laboratory experiment demonstrated that the amount by volume of the sludge to be added to sea-water must be less than 0·5 per cent. if nuisance is not to arise. This was only possible if care was taken to let off at the top of the ebb. If too long time elapsed after the turn of the tide before discharge, the whole of the blackened water was not carried away and remained near the shore till the returning tide.

In view of the work of McKee undertaken at Letts's suggestion, and quoted by the latter in a recent paper† it would appear most probable that the persistent odour of a mixture of sludge and sea-water is due largely, at any rate, to the production of sulphuretted hydrogen through the reduction of sulphates. In presence of nitrates it appears reasonable to assume that rapid oxidation of the sulphuretted hydrogen would occur. The effect of sea-water on nitrification is, therefore, seen to be an important factor in conditioning the production or otherwise of nuisance, and consequently it becomes necessary more exactly to determine the conditions under which nitrification is retarded or inhibited by sea-water.

Further work is also desirable on the mutual inter-action of sulphides and nitrates under varying conditions and also on the sources of evil-smelling compounds in mixtures of sewage and sea-water. It is likely that malodorous compounds other than sulphuretted hydrogen are also produced by the decomposition of complex nitrogenous substances which may require the presence of nitrates for their rapid oxidation. The well-known effect of nitrates in preventing putrefaction on incubation would point to this conclusion.

Researches by the present writer and his assistants are in progress with the object of throwing further light on these points.

The laboratory work in connection with the investigation here recorded was carried out in the Public Health Department of the University of Manchester, when special provision has recently been made for the chemical and bacteriological study of sewage.

The thanks of the writer are due to the authorities of the Admiralty for the facilities afforded in making the observation at Shotley, and for permission to publish the results.

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* Addendum to Section I. of Report, p. 455.

† "On Effluvium Nuisances, more especially such as occur in Tidal Localities. *Journal of the Royal Institute of Public Health*, February, 1908.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

SHOTLEY POINT.

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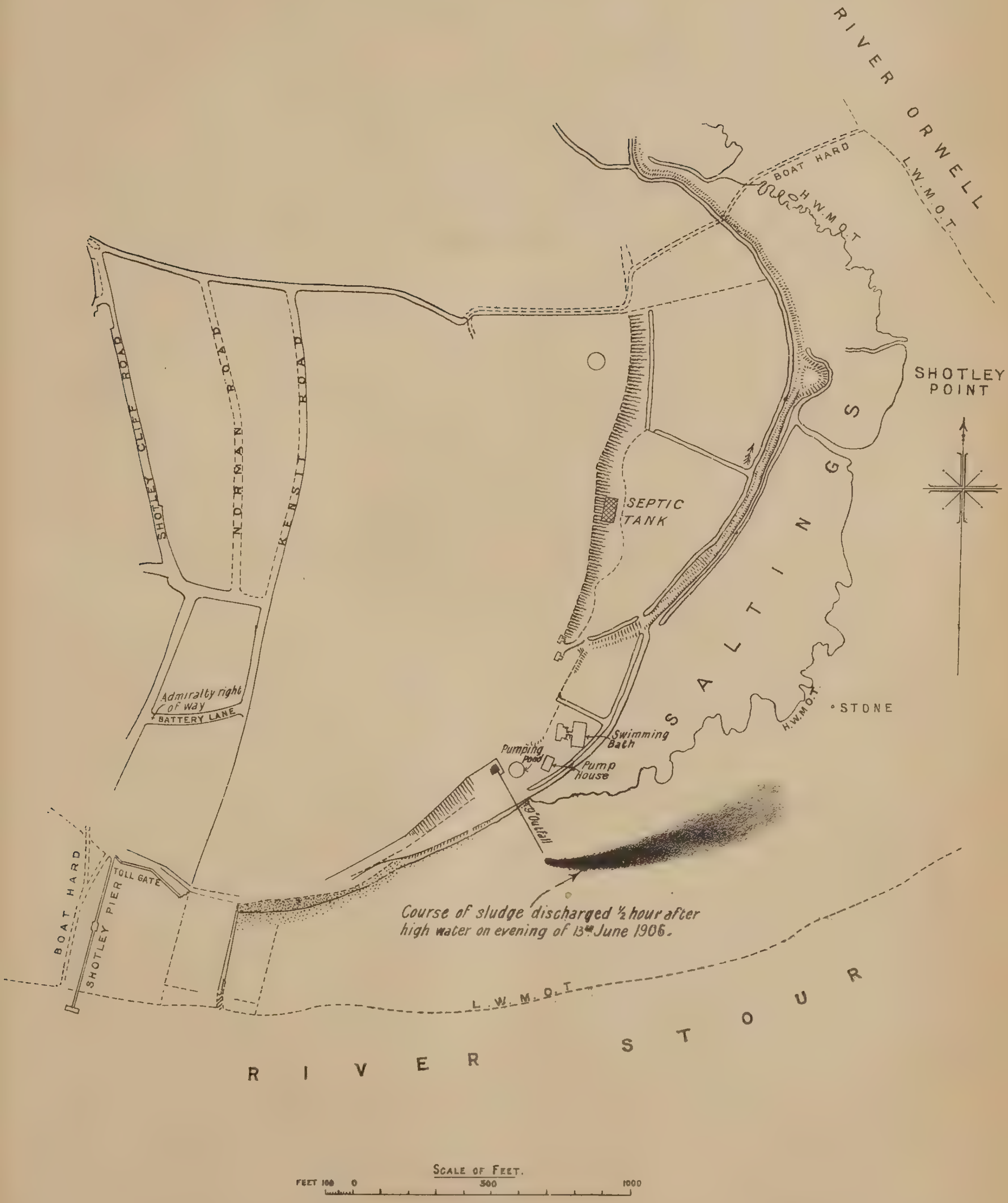

Course of sludge discharged ½ hour after high water on evening of 13th June 1906.

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ROYAL COMMISSION ON SEWAGE DISPOSAL.

FIFTH REPORT.

APPENDIX VII.

Circular Letter on the Subject of Standards for Sewage Effluents.

ROYAL COMMISSION ON SEWAGE DISPOSAL.

39, Victoria Street, Westminster, S.W.,
May, 1903.

STANDARDS FOR SEWAGE EFFLUENTS.

Sir,

The Commission are considering the question of standards for sewage effluents, and they would be much obliged if you would kindly state your views on the following questions:—

(A.)—Effluents which will pass into a Non-*drinking-water Stream.*

1. Are you in favour of fixed standards of purity ?

2. Assuming that you are in favour of standards, upon what principles do you consider they should be based ?

Standards may be roughly divided into the following classes*:—

(*a.*) A standard of non-putrescibility of an effluent upon incubation, without any reference to the organic matter which the effluent contains, or to the rate at which it would take up oxygen from surrounding water.

(*b.*) A standard of non-putrescibility, having regard also to the rate at which oxygen is taken up from water.

(*c.*) A standard like the provisional one of the Mersey and Irwell Joint Committee. Such a standard may be referred to, for purposes of comparison, as an absolute standard.

(*d.*) A standard depending upon some ratio, *e.g.*, the ratio of oxidized to unoxidized nitrogen, or—a modification of this—ratio of oxidized to albuminoid nitrogen.

The Commission feel it is important to bear in mind the fact, which has sometimes been overlooked, that a standard which is based entirely on the amount of organic matter remaining in an effluent is open to the objection that the residual organic matter in an effluent which is derived from a strong sewage is less fermentable, and has a less tendency to take up oxygen than the same weight of organic matter remaining in an effluent which is derived from a weak sewage.

It may also be necessary to consider the effect of an effluent upon the bed of a stream, as, *e.g.*, in encouraging plant growth.

3. Assuming that you consider it desirable that a standard should be based—in whole or in part—upon the rate at which an effluent takes up oxygen from surrounding water, how would you propose that such a test should be carried out, having regard to (*a*) accuracy; (*b*) simplicity; and (*c*) to obtaining the desired result in the shortest possible time ?

3*a*. Further what standard of absorption of *dissolved* oxygen (*i.e.*, what figures) would you suggest as a good working standard, and what are your reasons for this ?

4. If you are opposed to any definite standard, would you kindly state your reasons ?

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* NOTE.—It is assumed that suspended solids are either absent, or present in small quantity only, say not exceeding 3 or 4 parts per 100,000 by weight of effluent.

(B.)—*Effluents which may pass into a Drinking-water Stream.*

5. Assuming that you are in favour of standards, do you consider that a higher standard should be required in regard to effluents entering a stream from which drinking water is obtained, and if so, what standard would you propose for those cases?

6. If you have grounds for thinking that it is possible to sterilize sewage effluents, the Commission would be glad if you would state them.

The Commission may add that although the condition of many streams in the country at present is such that the addition of some more or less impure sewage effluent to the already polluted water might be considered by some to be a matter of comparatively small moment, they are advised that the state of the stream cannot lawfully be taken into account in considering whether an effluent infringes the provisions of the Rivers Pollution Prevention Act.

The Commission also desire me to say that they would be glad to know whether you have made any observations to ascertain whether it is easier to treat on a given area of land or filter a small volume of a strong sewage or a larger volume of a weak sewage, the total amount of organic matter in each volume being equal. If so, may I request that you will kindly furnish the Commission with the results of these observations.

I am, Sir,
Your obedient Servant,
F. J. Willis,
Secretary.

REPLIES TO CIRCULAR LETTER.

Mr. W. E. ADENEY, D.Sc., A.R.C.Sc.I., F.I.C., Curator and Examiner in Chemistry in the Royal University of Ireland.

Royal University,
Chemical Laboratory,
Dublin, August 31st, 1903.

Standards for Sewage Effluents.

To the Secretary,
Royal Commission on Sewage Disposal.

Sir,

I beg to submit to you the subjoined statement giving my views on the questions which you addressed to me in your printed communication of May last, in reference to Standards for Sewage Effluents.

(A) Effluents which will pass into a non-drinking water-stream.

I am in favour of standards of purity suitably graduated to meet local circumstances and requirements.

I would suggest that effluents to be discharged into a non-drinking-water stream should be classified into four groups according to the four general conditions of the average daily dry weather flow of the effluents being very large, large, small and very small, in proportion to the minimum dry weather flow of the streams into which they must be passed.

I would define for the purpose of this classification, the conditions of very large, large, small and very small, flow, to be when the proportions of average daily dry weather flow of effluents and the minimum dry weather flow of the streams are, respectively, as follows :—

(very large)	as 1 : 5 or greater
(large)	as 1 : 5 to 1 : 15
(small)	as 1 : 15 to 1 : 25
(very small)	less than 1 : 25

I base this classification upon what I have found by experiment to be the minimum dilution with tap water required to effect the complete carbon oxidation of the organic matters in an exceptionally foul sewage, and in an average town sewage, after the separation from them of the suspended matters by passing them through ordinary paper filters (see accompanying paper on Dissolved Gases and Fermentative Changes, in Addenda, pp. 49, *et seq.*).

A different standard of purity would be required for each group of effluents.

I am strongly of opinion that these standards should be formulated in reference to such chemical methods as are capable of yielding the most definite and accurate results practically obtainable.

When an effluent has been classified, and from time to time carefully examined by exact methods, its condition can be checked by simple and rapidly performed tests that can be carried out by comparatively untrained persons, or by officials not having at their disposal good laboratory accommodation. The tests I refer to are the determination of dissolved oxygen by a suitable volumetric method, to ascertain the rate of absorption of that gas in the effluent, and the determination of ammonia and oxidised nitrogen, to check the character of the fermentation.

For exact examination, accurate determinations should in my opinion be made of the products of the complete aërobic fermentation of the fermentative substances in an effluent, and of the oxygen absorbed during the process, for the simple reason that it is the fermentative substances, in terms of the amount and rate of absorption of oxygen, with the accompanying quantities of the carbonic acid and ammonia, at first formed, and with those of nitrous, nitric and carbonic acids, afterwards formed, which are required to be known, to estimate the influence of an effluent upon the waters of a stream into which it is to be discharged.

No fermentative changes other than those which take place under aërobic conditions should be considered as allowable in any stream, and sufficient work has been done to show that the course and products of aërobic fermentation of organic substances, and of ammonium compounds, are practically constant in character and quantity, respectively. In the evidence which I had the honour of laying before the Commission some five years since, I referred to two papers in which a considerable number of experiments are recorded all of which go to show that the aërobic fermentations of organic substances and of ammonium compounds, practically consists of a slow combustion in two progressive stages, in the first of which the organic matters are oxidised into carbonic acid, ammonia and water, comparatively very small quantities of humus-like colouring matters being also formed. The carbonic acid formed accounts for about 90 per cent. of the total carbon, and the ammonia for about 95 per cent. of the nitrogen, in the organic substances originally present.

After the first stage of combustion is completed, the second stage, that of the ammonia and of any peaty or humus substances, either originally present, or formed during the first stage of combustion, commences, the products being nitrous and nitric acids, and small quantities of carbonic acid.

The first stage of combustion may be fittingly termed the carbon combustion or oxidation stage, and the second, the nitrogen combustion or oxidation stage.

Thus the course of aërobic fermentation in an effluent is extremely simple and constant. The organisms in the effluent practically behave as constant chemical factors, with the result that the carbonic acid and ammonia formed, and the oxygen absorbed, during the carbon combustion stage are practically constant for similar quantities of organic substances originally present in an effluent; and the oxygen absorbed and nitric acid formed, during the nitrogen combustion stage, are likewise constant for similar quantities of ammonia originally present. Difference of species of organisms does not appreciably affect the quantities of inorganic products of combustion, nor of the oxygen absorbed.

Dr. Adeney.

The experiments upon which the foregoing statements are based will be found recorded in the accompanying two papers on Dissolved Gases and Fermentative Changes, published in the Transactions of the Royal Dublin Society in 1895 and 1896. (*See* Addenda, pp. 49 *et seq.*)

In the third accompanying paper the application of the Aeration Method of analysis to the study of river waters is discussed. (*See* Addenda, p. 95.)

The standards which I would suggest for effluents might be formulated as follows:—

Standard 1. Effluents of class 1 must be of the highest purity practically obtainable, that is to say, the carbon combustion stage should have been completed, and the nitrogen combustion decidedly commenced; and when a sample of it is mixed with four volumes of good tap water, the mixture well aerated, and kept out of contact with air for 24 hours, at about 60 degrees Fahr. the dissolved oxygen remaining in the mixture should not be less than $\frac{3}{10}$ths the volume of atmospheric nitrogen in the same.

Standard 2. Effluents of class 2 should be so far purified that when a sample is mixed with nine volumes of good tap water, and the mixture aerated and kept out of contact with air for 24 hours at about 60 degrees Fahr., the amount of dissolved oxygen in the mixture should not be less than $\frac{3}{10}$ths that of the dissolved atmospheric nitrogen in the same; and that when a portion of the mixture is further kept until all the dissolved oxygen is absorbed, the nitrogen combustion stage should have commenced.

Standard 3. Effluents of class 3 should satisfy similar conditions as those suggested for class 2, when mixed with 19 volumes of good tap water.

Standard 4. Effluents of class 4 should also behave similarly to those suggested for class 2, when mixed with 29 volumes of good tap water.

The foregoing standards are based upon the assumption that all sewage effluents discharged into streams must be free from antiseptics, at least from quantities sufficient to effect any retarding influence upon the fermentative changes set up by the micro-organisms therein.

(B) Effluents which may pass into a drinking-water stream.

I am of opinion that the standard of purity for effluents to be discharged into drinking-water streams should certainly not be less under any circumstances than the Standard 1 above suggested, and in all probability the standard should be higher to ensure bacteriological safety. Experience would seem to warrant the assumption that if the greater portion of inorganic nitrogen in an effluent exists as nitric nitrogen, *as a result of slow and careful filtration*, the effluent may be considered as bacteriologically safe. The standard therefore for these effluents might well require such careful filtration that the greater portion of its inorganic nitrogen should exist in the oxidised condition.

With reference to the general question of the influence of effluents in encouraging plant growth along beds of streams with properly-purified effluents, I do not anticipate any special trouble in the case of fresh-water streams.

When, however, an effluent is continuously discharged in appreciable quantities into sea water, the question may become a very serious one indeed, as we have ample evidence to show in the neighbourhood of Dublin, where the sea lettuce or ulva latissima grows luxuriously as a result of sewage being discharged on to foreshores under unsuitable tidal conditions.

The whole subject of the properties of the ulva latissima and the conditions which encourage its growth, has been most carefully studied by Professor Letts, of Belfast, and he, therefore, more than any other worker as far as I know, is in a position to give the Commission valuable information upon it, and I understand it is his intention so to do.

I am, Sir,
Your obedient servant,
W. E. ADENEY.

Mr. SIDNEY BARWISE, M.D., D.P.H., Medical Officer of Health to the Derbyshire County Council.

County Offices,
St. Mary's Gate, Derby.
June 29th, 1903.

SIR,

I regret that owing to illness I have not had an opportunity before this of replying to your letter of May.

I have now had time to consider the various questions you sent me and beg to reply as follows:—

(A).— Effluents which will pass into a non-drinking water stream.

1. I am in favour of standards of purity being fixed by some Central Authority *as a general guide* to the various Sanitary Authorities dealing with the question ot sewage purification. I doubt whether it would be wise to fix absolutely and irrevocably a standard in an Act of Parliament, because the circumstances through the country are so different, and a standard which might legitimately be adopted in the lower reaches of a watershed might not come up to what might be necessary in the upper reaches, particularly where tributary streams are derived from densely-populated districts. Another reason why the standard should be only one adopted as a general guide is that in the future new methods of analysis may be devised and better processes of purification be brought out, and the standard from time to time should be capable of being revised. It should also be made clear that, in mentioning any standard, it is a *minimum* standard.

2. In fixing a standard of purity, I think that it is not public policy at present to fix the standard too high. I think, however, that for Derbyshire it should be higher than that suggested by the Mersey and Irwell Joint Board, and in the future as works become more perfect it may be raised. Such a standard ought to be so high that any authority complying with it will not cause nuisance by polluting streams. At the same time it should not be so high as to put an unnecessary burden upon the sanitary authorities who have to comply with it. I believe that the standard of purity that we have adopted is a reasonable one at the present moment for Derbyshire, and that it complies with the two conditions I have laid down. I admit that authorities who have carried out modern works are getting much better effluents than our standard suggests, and there are circumstances which may require that higher purification being maintained, as where the stream into which the effluent is turned is a small one flowing through such populous districts as there are in Staffordshire. For instance, the effluent from Langwith Colliery Houses rarely contains more albuminoid ammonia than ·03 parts per 100,000, the last sample I analysed containing only ·01 parts per 100,000 of albuminoid ammonia, and as will be seen from the Return sent herewith, the first three effluents on the list all contained ·05 parts per 100,000 of albuminoid ammonia, and from ·7 to 2·8 parts per 100,000 of nitrogen as nitrates. I do not think that a standard of albuminoid ammonia or oxygen absorbed alone is reliable, unless the nitrogen as nitrates is also taken into consideration.

On the outside of the Return of Sewage Effluents issued by the Derbyshire County Council we indicate as a provisional standard for the guide of the authorities the following:—

Albuminoid Ammonia.—A good effluent is one which contains less than 0·1 parts per 100,000 of albuminoid ammonia.

Nitrogen as Nitrates.—An effluent should contain more than ·5 parts per 100,000 of nitrogen as nitrates. The nitrates are produced by the action of the oxygen of the air in the pores of the land or intermittent filters. The amount of nitrogen oxidized to nitrates is the best index of the efficiency of the action of the land or filters.

Incubator Test.—A good effluent should be so thoroughly oxidized that it does not absorb more oxygen after incubation for one week than it does at the time of collection

Shake Test.—A simple test, which can be readily applied, is to shake vigorously for one minute a bottle half filled with effluent. All frothing should disappear in three seconds.

Opacity Test.—A good effluent is one which is so transparent that Pearl type can be read by a person with normal sight, through a column 10 inches in depth.

As will be seen we inform the authorities of the albuminoid ammonia, the nitrogen as nitrates, and the result of the incubator test. The opacity and shake tests are made in the presence of the man in charge of the works, and, frequently the surveyors of the district councils in a rough way carry out the incubator test themselves. We do not pin our faith just to one factor alone.

3. I do not consider the suggestion as to the rate at which the effluent dissolves oxygen from surrounding water practicable, nor do I think it necessary as long as the effluent shows only a small amount of residual unoxidized organic matter, and a store of oxygen in the form of nitrates.

4. My reasons for objecting to a standard being established as a statutory limit have been explained in my answers to Question 1. This does not, however, take away the desirability of he minimum standard being published as a general guide for the information of local authorities.

Dr. Barwise.

(B).—*Effluents which may pass into a drinking-water stream.*

5. I am not in favour of a higher standard being required, where water is taken from a stream for drinking purposes. If the sewage works of a sanitary authority are a source of danger to the waterworks, I think that such waterworks should not be used. If anything further is required, it is that the effluent should be passed through a sand filter, but I do not think that the sanitary authority should be put to the expense of filtering the effluent; this should be done by the water company or sanitary authority using the river for drinking purposes.

I do not think it can be too clearly borne in mind that this filtration of the effluent can only take place with the dry weather flow, and the water company ought to be compelled to have some arrangement for warning them when the storm overflows, which are a danger to them, come into action, so that they may then cease taking water from the stream at such time. I ought, however, to say that this matter does not affect us in Derbyshire, as we have no authorities within the county taking water from any of our rivers.

6. The only sewage works I have seen at which the sewage is sterilized are at Trouville. Here, the solid portion obtained by evaporation and sterilization by heat was being sold as an artificial manure, while the fluid parts were being driven off into the air as steam. This is the only way which, in my opinion, sewage can be sterilized, and it is quite impracticable in this country.

The country is not prepared to spend the money for turning sewage into drinking water. Such a scheme in the British Isles is absolutely unnecessary.

With regard to the filtration of sewage, personally I believe it is an advantage to dilute an effluent with good water saturated with oxygen before it is passed through a percolating filter, *or* through a contact bed, but the difficulty of dealing with it on land after dilution makes it undesirable, therefore my suggestion is that it may be an advantage to dilute sewage, which has to be treated through percolating filters, after the anaërobic change has taken place in the septic tank. It would not be an advantage to dilute it before it went through the septic tank because it would necessitate the tank being unnecessarily large, and the oxygen in solution in the water would be wasted in the anaërobic process.

If the Commission wished, I have an opportunity of diluting a tank effluent with river water before it is filtered and I could have a series of examinations made day by day to illustrate this point one way or the other Or if the Commission wished to make the examinations themselves, the filters I refer to are about two miles from the County Laboratory, and I am sure that the Derbyshire County Council would be glad to place their laboratory at the disposal of the Commission for making the tests I refer to.

I wish the Commission to understand that the views expressed in this letter, are not merely those of myself personally, but are the views approved by the County Council.

SIDNEY BARWISE, M.D., B.Sc.

F J. Willis, Esq.

Enclosure to Dr. Barwise's Reply.

DERBYSHIRE COUNTY COUNCIL.

QUARTERLY RETURN OF EFFLUENTS FROM THE TREATMENT OF SEWAGE.

Explanation of Terms used.

Albuminoid Ammonia.—A good effluent is one which contains *less* than 0·1 part per 100,000 of Albuminoid Ammonia.

Nitrogen as Nitrates.—An effluent should contain *more* than ·5 parts per 100,000 of Nitrogen as Nitrates. The Nitrates are produced by the action of the Oxygen of the air in the pores of the Land or Intermittent Filters. The amount of Nitrogen oxidised to Nitrates is the best index of the efficiency of the action of the Land or Filters.

Incubator Test.—A good effluent should be so thoroughly oxidised that it does not absorb more Oxygen after incubation for one week than it does at the time of collection.

Shake Test.—A simple test which can be readily applied is to shake vigorously for one minute a bottle half filled with effluent. All frothing should disappear in three seconds.

Opacity Test.—A good effluent is one which is so transparent that Pearl type can be read by a person with normal sight through a column 10 inches in depth.

Dr. Barwise.

DERBYSHIRE

QUARTERLY RETURN OF EFFLUENTS

The figures refer to

No.	Description of Samples.	Method of Treatment.	Albuminoid Ammonia.
	ROTHER WATERSHED.		
1	Chesterfield R.D.C., Temple Normanton Effluent - May 21	Septic Tank and Percolating Filters	·05
2	Chesterfield Boro' New Filter Effluent - Mar. 26	Septic Tanks and Percolating Filter	·05
3	Chesterfield R.D.C., Arkwright Town Effluent - May 21	Septic Tank and Percolating Filters	·05
4	Chesterfield Boro' Land Effluent - Mar. 26	Septic Tanks and Land	·14
5	Chesterfield R.D.C., Heath Effluent - May 21	Septic Tank and Percolating Filters	·16
6	Chesterfield R.D.C., Tupton Effluent - May 21	Septic Tank and Percolating Filters	·18
7	Newbold & Dunston U.D.C. - Mar. 26	Land	·40
8	Bolsover U.D.C. Tank Effluent - Apr. 8	Septic Tank (Filters not in use)	·42
		Note.—Effluents Nos. 1 *to* 3	
	TRENT WATERSHED.		
1	Shardlow R.D.C., Stapleford & Sandiacre Outfall - Apr. 4	Tanks, Filters and Land	·06
2	Swadlincote U.D.C., No. 1 Outfall - Apr. 2	Land	·06
3	Burton-on-Trent Boro' Effluent - Mar. 28	Lime and Land	·08
4	Hartshorne & Seals R.D.C., Woodville Effluent - Apr. 2	Precipitation, Contact Beds and Land	·10
5	Blackwell R.D.C., South Normanton Tipper Filtrate - May 28	Septic Tank and Percolating Filter	·10
6	Chesterfield R.D.C., Stonebroom Effluent May 14	Tanks, Filters and Land	·12
7	Blackwell R.D.C., Tibshelf Effluent - May 14	Tanks and Land	·14
8	Blackwell R.D.C., South Normanton Tank Effluent - May 28	Septic Tanks	·21
9	Blackwell R.D.C., West Houses Village Outfall - May 28	Tank and Land	·24
10	Repton R.D.C., Castle Gresley, Burton Road - Apr. 2	Cesspool Tank	·28
11	Swadlincote U.D.C., No. 2 Outfall - Apr. 2	Land	·28
12	Long Eaton U.D.C., Tank Effluent - Apr. 4	Precipitation	·35
13	Repton R.D.C., Castle Gresley Outfall - Apr. 2	Land	·35
14	Bakewell R.D.C., Cromford Effluent - May 27	Tank	·5
15	Chesterfield R.D.C., Morton Effluent - May 14	Tanks, Filters and Land	·75
		Note.—Effluents Nos. 1 *to* 5	
	MERSEY & IRWELL WATERSHED.		
1	Hayfield R.D.C., Hayfield Effluent - Apr. 23	Tanks and Land	·01
2	New Mills U.D.C. Effluent - Apr. 23	Tanks, Filters, and Land	·08
3	Chapel-en-le-Frith R.D.C., Chapel-en-le-Frith Effluent Apr. 23	Tanks and Land	·12
4	Glossop Boro' Effluent - June 3	Tanks and Filters (Clinker)	·14
		Note.—Effluents Nos. 1 *and* 2	

This table does not include the analyses of crude sewage

COUNTY COUNCIL.

Dr. Barwise.

FROM THE TREATMENT OF SEWAGE.

parts per 100,000.

Incubator Test.			Nitrogen as Nitrates. *The higher the figure the better the effluent.*	**Opacity.** Depth through which Pearl Type can be read.	Remarks on appearance of Effluent Weather, &c.
Oxygen absorbed in 3 minutes.					
Before Incubation. A.	After 7 days Incubation at 80° F. B.	**Putrescibility** measured as Oxygen required. B *minus* A.			
·03	·03	nil	·70	12″	Clear. No smell. Fine weather.
·16	·20	·04	·75	10″	Very clear. No smell. Showery weather.
·63	·70	·07	2·8	10″	Clear. No smell. Fine weather.
·23	·26	·03	trace	5″	Clear Slight smell. Showery weather.
·16	·13	nil	1·25	10″	Clear. No smell. Fine weather.
·03	·10	·07	2·5	9″	Clear. No smell. Fine weather.
·50	·56	·06	nil	1¼″	Sewage. Bad smell. Showery weather.
·66	1·63	·97	nil	1″	Foul Pollution. Slight showers.
are satisfactory.					
·01	20	·19	1 25	11″	Clear. No smell. Showery weather.
·13	·10	nil	1·5	10″	Clear. No smell. Showery weather.
·30	·30	nil	trace	4″	Slight smell. Showery weather.
·16	·166	·006	trace	5½″	Sewage smell. Fairly clear. Showery weather.
·03	·10	·07	2·0	8″	No Smell. Fine weather.
·70	·80	·10	nil	6″	Clear. Slight smell. Fine after storms.
·20	·26	·06	·90	4¼″	Clear. No smell. Fine after storms.
·53	1·4	·87	nil	1″	Smell. Fine weather.
·73	2·7	1·97	nil	2″	Suspended matter. Sewage smell. Fine weather.
·7	1·63	·93	nil	1¼″	Sewage. Foul smell. Showery weather.
·48	2·63	2·15	nil	1″	Crude sewage. Foul smell. Showery weather.
·36	2·70	2·34	nil	½″	Opalescent. No smell. Showery weather.
·60	3·90	3·30	nil	¾″	Crude sewage. Foul smell. showery weather.
					Sewage smell. Fine weather.
·85	1·9	1·05	nil	5″	Sewage smell. Fine after storms.
are satisfactory.					
·3	·23	nil	nil	9″	Clear. No smell. Fine weather.
·16	·2	·04	·75	10″	Clear. No smell. Fine weather.
·40	·53	·13	trace	2¾″	Fungus. Slight smell. Fine weather.
·06	·42	·36	nil	7½″	Clear. No smell. Fine weather.
are satisfactory.					

where no purification works have yet been constructed.

SIDNEY BARWISE, M.D., B.Sc.,

County Medical Officer.

Mr. J. CARTER BELL, A.R.S.M., &c., Analyst for the County of Chester and for the County Boroughs of Salford, Birkenhead, Congleton, Stalybridge, and Glossop.

The Cliff, Higher Broughton, Manchester,
July 29th, 1903.

Dear Sir,

I must apologise for not answering your letter before, but in May I was on the Continent, and on my return your letter was mislaid and thus escaped my memory. I give the following answer to the questions :—

No. 1 Question. Yes.

No. 2. A standard of incubation, and the amount of oxygen required to oxidise the organic matter. I think the Mersey and Irwell standard a fairly good standard, but ·1 for albuminoid ammonia is rather too severe, and no large sewage works could obtain that standard day after day.

No. 3. Dr. Thresh's method, described in the Journal of the Chemical Society, 1890, page 85.

No. 5. I should be strongly against any sewage effluent entering a stream which is used for drinking purposes.

No. 6. I do not think it possible to sterilise sewage effluents without very considerable expense.

My experience has been that it is easier to treat a given quantity of weak sewage upon a filter than a strong solution of sewage. When the dark effluent goes on to the filters with an oxygen number of 4·0 grains to the gallon, it will only be reduced to about 50 per cent., but when the dark effluent goes on to the filter at 20 grains to the gallon the filtered effluent will be as low as 0·5 grains of oxygen to the gallon.

I remain,
Yours truly,
J. CARTER BELL.

Mr. A. WYNTER BLYTH, M.R.C.S., F.C.S., F.I.C., etc

Question 1. A standard fixed by statute and which could not be varied save by an amendment of the law would be highly objectionable, for the obvious reason, that no immediate advantage could be taken of any new discovery in either the treatment of effluents or of testing effluents.

On the other hand, I am in favour of definite standards; such might be conveniently fixed by the County Councils as advised by their expert officers, with possibly confirmation by the Local Government Board. The local conditions of watersheds vary so considerably that it probably is not practical to work a uniform standard for the whole kingdom.

It is also an acknowledged fact that exceptional weather, such as excessive rainfall, will so interfere with systems of purification as to render it practically impossible for brief periods of time to conform to any standard; therefore in the fixing of standards provision should be made for such temporary conditions, and the standard should only be considered applicable under ordinary states of weather.

Question 2. With regard to the standard to be fixed, I am in favour of the non-putrescibility standard of the Mersey and Irwell Joint Committee with modifications. The Committee recommend the incubation to be carried on for too long a period, viz., about a week. I would suggest that the incubation be shortened to not more than three days.

I also consider that regard should be taken to the influence of an effluent upon the oxygen of the stream, and the best method to ascertain this is to estimate the oxygen dissolved in the water of the stream above the effluent and at various points below the effluent. Simple methods of this "differential method of estimating oxygen in water" are described at pages 533–535 in the writer's book on "Foods" (last edition, 1903). Such determinations should in part be made at or on the stream itself, thus avoiding change in transit.

3a. The writer is not at the present moment prepared to suggest a standard of absorption for dissolved oxygen. Such a standard might be fixed, but it would require considerable practical study of a number of effluents and their effect on streams.

(B) Effluents which may pass into a drinking water stream.—In this case the standard must be a biological one, and such standards must not only be applied to streams used for drinking, but also to streams which are not necessarily drunk, but at the mouth of which shellfish of any kind are likely to be collected for food.

A. Wynter Blyth.

Professor FRANK CLOWES, D.Sc., F.I.C., CHEMIST TO THE LONDON COUNTY COUNCIL.

Chemical and Gas Department,
40, Craven Street, W.C.,
June 9th, 1903.

DEAR SIR,

Referring to your circular letter respecting standards for sewage effluents, dated May, 1903, the only points upon which I can offer any opinion are the following :—

Question.	Answer.
1. Are you in favour of fixed standards of purity ?	No.
4. If you are opposed to any definite standard would you kindly state your reasons ?	I am in favour of the adoption of the Commissioners' recommendation published on p. xxiv. of their third report. If adopted, I think that the central authority would be more effective without a standard of purity having been fixed.

In the event, however, of the Royal Commission deciding to recommend that a standard of purity be fixed, I submit the following answers for their consideration :—

Question	Answer.
2. Assuming that you are in favour of standards, upon what principles do you consider they should be based ?	Upon class (b): "A standard of non-putrescibility, having regard also to the rate at which oxygen is taken up from water."
5. Assuming that you are in favour of standards, do you consider that a higher standard should be required in regard to effluents entering a stream from which drinking water is obtained, and if so, what standard would you propose for those cases ?	A higher standard should be required for effluents entering a drinking-water stream than for those entering a non-drinking-water stream
6. If you have grounds for thinking that it is possible to sterilise sewage effluents the Commission would be glad if you would state them.	Owing to the uncertainty of complete sterilisation being effected, the process is of doubtful value.

Yours faithfully,

FRANK CLOWES,
Chemist.

F. J. Willis, Esq.,
Secretary,
The Royal Commission on Sewage Disposal,
39, Victoria Street, S.W.

Mr. PERCY COWARD, Chemist to the Huddersfield Corporation.

Sewage Disposal Works,
Deighton, Huddersfield,
June 9th, 1903.

SIR,

I beg to acknowledge the receipt of yours requesting my views with regard to fixed standards for sewage effluents.

I have considered this question from one aspect only, viz., that in which the effluent passes into a non-drinking water stream.

I am decidedly opposed to any definite chemical standard being adopted, and consider that each case and district should be dealt with separately.

The stream into which an effluent is turned must be first considered. If an effluent which abstracts free oxygen from water is turned into a rapid-flowing stream which is constantly passing over weirs and places where the water is broken up and brought into intimate contact with the air, I do not consider that the fact of the effluent absorbing dissolved oxygen should alone condemn it. However, in case of effluents being turned into such waterways as the Manchester Ship Canal, a deep and slow-flowing body of water, the fact of them absorbing dissolved oxygen (above a certain rate), would be of great importance. Also, effluents vary very much in their character. An effluent resulting from the purification of a weak domestic sewage cannot with any reliance be judged by standards used for effluents from the purification of sewage containing trade waste. The amount of oxygen absorbed from permanganate may be small in the former case, and yet the effluent may be of a putrescible character, whilst in the latter case the oxygen absorption may be high and the effluent of a non-putrescible and harmless character. Therefore, an effluent cannot be either accepted or rejected by the oxygen absorption test alone.

The ratio of oxidised to unoxidised nitrogen in an effluent is no indication of the amount of nitrogenous matter which has been eliminated from the sewage, as in certain methods of treatment a large amount of nitrogen is liberated in a free state. A continuous filter will produce a far greater quantity of nitrates than contact beds, although the percentage of nitrogen removed be the same.

Owing to the composition and nature of sewages in different towns and villages varying to such a great extent, and also to the different methods adopted for their purification, I do not consider it possible, without injustice, to adopt certain chemical standards to be universally applied. At the same time, I am of opinion that an effluent which does not develope any objectionable smell after being kept in a bottle completely filled and in an incubator at 80° Fahr., for seven days, is sufficiently pure to turn into a rapid-flowing stream, provided the effluent contains ordinary micro-organisms in an active state.

Chemical analyses and tests, whilst being of extreme use and almost a necessity to those engaged upon the purification of sewage at a works, are of much less value for the comparison of sewage and effluents from various towns, &c.

I am,
Yours faithfully,
PERCY COWARD.

F. J. Willis, Esq.,
Secretary,
Royal Commisson on Sewage Disposal.

Mr. W. J. DIBDIN, F.I.C., F.C.S., ANALYTICAL AND CONSULTING CHEMIST.

2, Edinburgh Mansions, Howick Place,
Victoria Street, Westminster,
May 21st, 1903

STANDARDS FOR SEWAGE EFFLUENTS.

DEAR SIR,

In reply to your inquiries, I beg to submit the following observations, viz. :—

1. I do not think that a hard-and-fast line should be drawn, but that there should be a margin allowed to meet exceptional occasions.

2. I consider the Mersey and Irwell Joint Committee standard as very reasonable under ordinary circumstances, but the addition to this of a method of determining the capability of the effluent to retain at least 50 per cent. of its dissolved oxygen after thorough artificial aeration, for at least 24 hours, will provide a further safeguard (*see* my Report on the condition of the River Thames already given in my evidence), as indicating the capability of the river water to support fish life and healthy plant growth.

3. I suggest that the only reliable method is to employ the gasometric process in the laboratory. The error involved in the changes taking place in the interval between the collection of the sample and its examination would be less than that due to any of the volumetric processes, which give very variable results when employed on impure waters.

The process employed by me for this purpose has been already described in my evidence. When a survey of a river is being made, the process of Dr. Thresh is a useful indicator of the varying condition of the stream.

3a. See answer to 2, viz. :—A good effluent should retain at least 50 per cent. of the dissolved oxygen after complete artificial aeration.

4 and 5. I consider that the highest possible quality of effluent should be required when the discharge takes place into a stream which is used at a lower point for drinking purposes, and for this reason I think that a standard is not advisable, as it might serve as an excuse for discharging an effluent inferior to that which might reasonably be expected and obtained.

6. I look upon the absolute sterilisation of sewage effluents as unattainable in practice, however desirable in theory.

The remarkably variable nature of sewage renders observations such as that referred to in the concluding portion of your letter very difficult to answer. In the case of precipitation it is, as I pointed out in 1887, advisable to keep the sewage as strong as possible, but in bacterial treatment I consider that the more dilute the sewage the greater will be the quantity of dissolved oxygen brought into contact with it, and the greater scope afforded for the action of the aerobic bacteria. If the sewage could be sufficiently diluted the whole of the work could be effected without putrefactive changes taking place.

I am, dear Sir,
Yours faithfully,
W. J DIBDIN.

F. J. Willis, Esq.,
Secretary,
Royal Commission on Sewage Disposal.

Mr. GILBERT J. FOWLER, M.Sc., F.I.C., SUPERINTENDENT AND CHEMIST, MANCHESTER CORPORATION SEWAGE WORKS.

OBSERVATIONS *re* STANDARDS FOR SEWAGE EFFLUENTS.

(A) *Effluents which will pass into a non-drinking-water stream.*

(1) Are you in favour of fixed standards of purity?

Yes, with the understanding that they are interpreted in a reasonable manner, and used more with the object of creating a spirit of emulation among authorities than of forcing all into rigid compliance irrespective of local conditions.

(2) Assuming you are in favour of standards, upon what principles do you consider they should be based?

Class (a) is not a satisfactory standard, as non-putrescibility upon incubation may merely mean that the effluent is temporarily sterilised, *e.g.*, by the excess of lime, the effect of the sterilising agent disappearing on dilution with river water.

(b) This is the most reasonable and satisfactory standard in every way.

(c) The provisional standard of the Mersey and Irwell Joint Committee is only useful in the case of works where purely domestic sewage of an average strength is treated. With sewage containing manufacturing waste or with very strong domestic sewage such standards may be very misleading.

(d) This standard would be interfered with by certain nitrogenous trade effluents. For purely domestic sewage it would be useful, but involves more analytical work than (b), and would serve chiefly as an amplification of this.

As regards the possibility of an effluent encouraging *plant growth* in a stream, this will depend largely, no doubt, on the quantity of nitrates present in an effluent. If a highly-nitrated effluent passes into an already polluted stream, *e.g.*, the Manchester Ship Canal, the nitrates are of value in oxidising some of the impurities present. If the stream is in good condition and weeds and water plants are growing in it, it will probably be best for the stream and more economical if the nitrates are used for agricultural purposes, or for purifying a further quantity of less highly-oxidised effluent before being admitted to the stream.

Method of applying dissolved oxygen test.

(3) The test may be carried out by mixing one volume of the effluent to be analysed with nine volumes of tap water which has been well shaken with air. After standing about a quarter of an hour to allow any air bubbles to escape, the dissolved oxygen can be determined in the mixture by Winkler's method* (*see* note at end), as modified by Rideal. A bottle containing enough of the mixture for a further determination, *e.g.*, 600 cc., is then placed in the incubator and allowed to remain for two days at 80° Fahr., and the dissolved oxygen is again determined after the bottle has been allowed to cool to room temperature. To allow for the expansion of the liquid during incubation, the bottle is provided with an indiarubber stopper through which passes a short piece of glass tubing. To this is attached about 4 inches of narrow indiarubber tubing, which is finally closed by a glass plug. In this way a certain amount of expansion of the liquid can take place without loss.

In important cases a control determination should be made with tap water alone, in order to allow for any loss of dissolved oxygen on incubation.

Standard of absorption of dissolved oxygen.

(3a) From a number of results which have accumulated, I should be inclined to pass an effluent which, on incubation with nine times its volume of aerated tap-water at 80° Fahr. for 48 hours, absorbed not more than 30 per cent. of the total quantity of dissolved oxygen present in the mixture before incubation.

Standard for effluents entering drinking-water stream.

In the first place I consider that no water should be taken for drinking purposes from a stream which has received sewage or sewage effluents of any kind, without an adequate system of waterworks, filters, or some other means (*e.g.*, sterilisation by ozone) of safeguarding the water supply. In addition to the chemical standard of purity in the effluent as above-mentioned, I consider that a limit of bacterial purity should then be introduced.

Exactly what this should be is a matter for bacteriologists to settle. I would suggest as a limit such number of "b. coli" per cc., as having regard to dilution by river water in dry weather could with proper care be removed at the waterworks.

If possible, however, the water supply should be drawn from some entirely unpolluted source. I do not think it possible in the majority of cases to effectively sterilise sewage effluents.

GILBERT J. FOWLER,
Superintendent and Chemist,
Manchester Corporation Sewage Works.

Dated June 19th, 1903.

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* NOTE.—This method has been found to be rather quicker than the Thresh method and less liable to be interfered with by certain trade effluents. The Thresh method gives very trustworthy results in the majority of cases, and both the Thresh and Winkler methods require less complicated apparatus and simpler chemicals than methods involving the use of indigo and hyposulphite. Have not had much experience of the Ramsay method, but doubt whether it is of sufficient accuracy for standard work. The cuprous chloride is also rather difficult to prepare and to dissolve.

Mr. J. GARFIELD, Assoc.M.Inst.C.E., Engineer of the Bradford Sewage Works.

Replies to Questions on "Standards for Sewage Effluents."

(A) *Effluents which will pass into a non-drinking-water stream*

1. No.

2. (a) The incubation test alone does not appear to show whether the effluent is liable to putrescence when discharged into a stream.

(b) This basis is more reliable, but in the present state of our knowledge cannot be taken as definite.

(c) I know of no means by which the specific organic substances in effluents can be determined with any degree of accuracy. The amount of oxygen absorbed from permanganate in four hours appears to vary very much with different kinds of organic matter. The albuminoid nitrogen figure is not the expression of an absolute fact. The amount of nitrogen present as nitrates does not appear to give reliable evidence as to the extent to which purification has progressed.

(d) The ratios are no guide to the fermentable condition of the effluent. It is possible to remove regularly and continuously 90 to 95 per cent. of the albuminoid nitrogen from ewage and produce an effluent containing no oxidized nitrogen.

The fact that the residual organic matter in an effluent is more or less easily fermentable according to the origin of the effluent, is yet another objection to an absolute standard.

The effect of an effluent upon the bed of a stream appears to give a good indication of the polluting effect of the effluent, but in the present state of our knowledge, it is not possible to base any standard upon it.

3. The data available at the present time, as to the rate at which an effluent takes up oxygen from the surrounding water, are not sufficient whereon to base a standard.

3a. See 3.

4. A "definite standard" cannot be of value in the present state of our knowledge. The oxidisable matter in sewage is very complex. We have no data to decide upon the quality as well as the quantity of organic matter. The effect of any particular effluent upon a large swiftly-running stream is not the same as upon a small sluggish stream. The circumstances of the case, with special reference to the means available for purification and the matter to be purified, should be taken into consideration. One Sanitary Authority is able to produce with ease an effluent which another Authority could not attain except at enormous expense.

(B) *Effluents which may pass into a drinking-water stream.*

5. The difficulty of preventing untreated sewage passing into streams in times of heavy rain appears to preclude the use of the water of such a stream for drinking purposes. Could this be got over, it may not be impossible in the future to purify sewage so as to free it from pathogenic germs.

With regard to the purification of equal quantities of organic matter contained in large and small volumes of sewage, on a given area of filter. It would appear from observations I have made that in one case (a small sewage disposal works) the pollution of a stream was less in summer, when the volume of sewage was small, than in the winter, when the volume was larger. I must add that, in this case, the area of the filter was not sufficiently large to deal with the winter flow, part passing untreated into the stream, whereas the summer flow was all filtered.

On the other hand, cases occur where it is of advantage to dilute the sewage before filtration to obtain the best results.

I must add that these observations were made in a cursory manner, no strict investigations being carried out.

J. Garfield.

City of Bradford Sewage Department,
July 27th, 1903.

Mr. CHARLES E. GROVES, F.R.S., Chemist to the Thames Conservancy.

Sir,

In reply to your letter asking me to state my views as to "Standards for Sewage Effluents," I may perhaps be allowed to offer the following comments on the circular letter dated May, 1903 :

(A) *Effluents which will pass into a non-drinking-water stream.*

1. I am not in favour of "*fixed* standards of purity" for effluents which pass into "non-drinking-water" streams, but hold that each case should be considered separately :—

(a) Special regard should be paid to the relation between the volume of the effluent, and that of the stream ; that is, the volume of effluent discharged in a given time, and the volume of the stream passing the point of discharge in the same time, or in other words, the amount of dilution which the effluent undergoes.

(b) The amount of aeration and the rapidity of flow of the stream receiving the effluent are factors of importance, as these will affect the rate of oxidation of the polluting nitrogenous organic matter.

2. In deciding on the standard to be employed for any individual sewage effluent, I am of opinion :—

(a) That the method of "ultimate analysis," that is, the determination of the exact amount of carbon and nitrogen, in the residue left on evaporation (however valuable it may be for *potable waters*), is, for sewage effluents, comparatively worthless, as seems to be indicated in the paragraph beginning, "The Commission feel it is important." . . .

(b) The various "permanganate methods" are also likely to give fallacious indications, notably in effluents from sewage farms which are working well and contain considerable quantities of *nitrites*. The latter by the permanganate method would be reckoned as putrescible organic matter.

(c) The "albuminoid ammonia" method, if carefully and methodically carried out, gives the best indication of the amount of easily putrescible nitrogenous organic matter in a sewage effluent, as not only have nitrites no influence on the result, but it also differentiates to a great extent between the easily oxidisable, and the "less fermentable" "residual organic matter."

3a. The "standard of absorption of dissolved oxygen" should not be less than 50 per cent. of saturation in the stream in the immediate neighbourhood of the effluent discharge. If much below this, the fish in the stream are likely to be affected.

This is important where certain kinds of trade refuse, "malt water," for instance, are mixed with the sewage effluent (or are allowed to flow directly into the stream).

Note.—I do not know whether the growth, in such streams, of enormous quantities of *Vorticellæ* in such cases, and its possible connection with deficiency of oxygen, has been considered by the Commission.

(B) *Effluents which may pass into a drinking-water stream.*

5. I am certainly of opinion that a far higher standard of purity should be exacted for effluents which pass into streams used as sources of drinking water, than in those of Class (A).

Here, again, I think the "standard" adopted for any given effluent (as in A) must depend in a great measure on the comparative volumes of the sewage effluent and of the stream, but even where the volume of the stream is very large compared with that of the effluent, the "albuminoid ammonia" in the effluent should never exceed 2·0 parts per million.

I may say that in the effluents from well-managed sewage farms on the Thames and its tributaries, above the water companies' intakes, the albuminoid ammonia is nominally 1·0 per million, or less.

6. I think it *most undesirable* to sterilise sewage effluents, even if it were possible to do so, as the purification, that is, the destruction of the nitrogenous organic matter of sewage, is effected entirely by biological action, and not by direct oxidation. The attempts made by the late Dr. Kanthack in this direction by treating the Maidenhead sewage with "electrozone" are an illustration of this. Of the samples of treated effluent which I examined, there were none which were completely sterilised, and the "cut" into which the "sterilised" effluent flowed became very foul, there being "very extensive fungoid growths along its whole course."

In conclusion, I may say that I am very strongly of opinion that no sewage effluent, however it may be treated, whether chemically, biologically, or by a combination of the two methods, should be discharged *directly* into a stream which is to be used as a source of drinking water, but should always be passed over land before being allowed to flow into that stream. We have no conclusive evidence that chemical or biological treatment, singly or combined, will destroy pathogenic bacteria in a sewage effluent, and it seems most desirable that the safeguard afforded by land treatment should, in all such cases, be adopted.

Charles E. Groves, F.R.S.,
Chemist to the Thames Conservancy.

Kennington Green, S.E.,
July 22nd, 1903.

Mr. E. HALLIWELL, F.I.C., Chief Inspector to the Ribble Joint Committee.

16, Walton's Parade,
Preston.
May 30th, 1903.

To the Chairman and Members of the Royal Commission on Sewage Disposal.

My Lord and Gentlemen,

Standards for Sewage Effluents.

I am not in favour of fixed standards.

My objections are as follow :—

(1) The standard ought to be determined upon the minimum amount of matter possible to cause pollution under the severest circumstances, and I hold that such a standard would be necessarily so strict that many effluents attaining the limit would be condemned, although such effluents might not be the cause of pollution.

I am assuming that a standard for effluents would be of such a value that a stream containing an effluent exceeding that limit would, under some circumstances, be either injurious to health, harmful to cattle or fish life, or objectionable for manufacturing purposes ; and I am of opinion that before condemning an effluent one ought, in order to prove pollution, to take other circumstances, such as volume of effluent, volume and flow of river both in the immediate vicinity, and at some distance, usages of the river, into consideration.

(2) The chemical and bacteriological effects, dependent upon the volume and nature of trade refuse, amount of fæcal and urinous matter, nature and volume of storm water, and street drainage in the crude sewage, are not known with sufficient precision to enable a standard to be fixed.

(3) If a standard were fixed and legalised, it would be extremely difficult to have such standards altered at any time, and sanitary science would be severely handicapped and limited.

(4) The standard cannot be determined upon any single constituent, and so many factors are necessary that it would be unworkable.

At the same time, I am of opinion that a working standard is advisable, so as to enable one to form a rough guide. Such a standard, though valuable, has not the force of law, and enables one to take other things into consideration before condemning a liquid.

Assuming that standards were fixed, I am of opinion that :—

(a) Is impossible ; in that the effluent itself may be in a putrescent stage, or would give rise to putrescence in liquids not themselves putrescent ;

(b) Not sufficiently definite, as the amount of water from which the oxygen is obtainable is too variable and indefinite ;

(c) Very useful as a provisional one, but other points have to be considered ;

(d) The ratio of oxidised nitrogen, unoxidised nitrogen, albuminoid nitrogen is on right lines, but factors (a), (b), and (c) ought to be taken into consideration at the same time.

I am, my Lord and Gentlemen,
Yours faithfully,
Edward Halliwell,
Chief Inspector.

Mr. W. H. HARRISON, B.Sc., Chemist to the Leeds Corporation.

Knostrop Sewage Works,
Leeds,
May 27th, 1903.

Dear Sir,

With reference to the request to state my views upon the subject of standards for sewage effluents, I beg to hand in the following statement :—

(*A.*) *Effluents which pass into a Non-drinking-water Stream.*

Question 1. I am not in favour of fixed standards of purity based upon limiting numerical values such as the present Mersey and Irwell standard, for the reason that different bacteriological processes produce effluents containing varying amounts of organic impurity as determined by the usual tests, the quantity of which is no safe criterion of the power the effluent has of resisting putrefactive changes, *e.g.*, the highest value I have obtained for the "oxygen absorbed in four hours" test in a non-putrescent effluent derived from double contact beds treating crude sewage is 1·62 parts per 100,000. Above that figure the effluents have invariably been putrescent; on the other hand, the effluents from a continuous filter treating crude sewage, and containing all its suspended matter, has been non-putrescent when its oxygen absorbed value has been as high as 2·30.

Again, an effluent which is non-putrescent in summer would probably in winter be found to be putrescent, although the values in both cases derived from tests are practically the same. Also, an effluent which at one time is non-putrescent with a given oxygen absorbed figure is sometimes found to be putrescent when giving a much lower value.

Question 2. What I consider to be a safe standard by which to judge effluents is a combination of the putrescibility upon incubation, and a determination of the rate at which dissolved oxygen is taken up. My reason for fixing upon this combination is that the comparison of the figures for the 3 mins. oxygen absorption before and after incubation is unreliable, even when urea is used to decompose nitrites, many effluents giving higher values after incubation than before, although remaining perfectly sweet. In all cases, however, where the effluent has been really putrescent there has been a great rate of absorption of dissolved oxygen, but when the effluent has remained perfectly sweet, although the oxygen absorbed values have increased on incubation, the rate of absorption of dissolved oxygen has been normal.

Some method of measuring the putrescibility of an effluent on incubation, other than by oxygen absorbed in 3 mins., is desirable. This might be done by a determination of sulphides, etc., in the incubated liquid.

Question 3. Any method of determining the "oxygen in solution" with an accuracy of ·5 cc. per litre can be utilised for testing effluents. The method used on these works, and which I consider to be the simplest and quickest, is that designed by Prof. Sir William Ramsay.

The effluent to be tested is shaken in a large bottle until saturated. The amount of dissolved oxygen is measured, and a well-stoppered bottle, holding about 150 cc., is completely filled with the aërated liquid and tightly stoppered and allowed to stand at the laboratory temperature for 24 hours. At the end of this period the dissolved oxygen is again determined, the difference being the amount absorbed.

I find it to be quite unnecessary to dilute the effluent with tap water, as a good effluent will not absorb more than 3 cc. of dissolved oxygen per litre.

In cases where results are wanted at once I find that determination of the "oxygen in solution" in the well-shaken effluent, and also in the effluent as it comes from the final filter or tank, as the case may be, may be taken instead of the above: the difference between these values being comparable to that obtained in the 24 hours' test :—

OXYGEN IN SOLUTION (cc.s. per litre).

Date 1903.	Effluents.																							
	When Saturated.								After standing 24 hours.								As obtained from filter.							
	Whittaker bed, unsettled.	Whittaker bed, sand-filtered.	Leeds bed, unsettled.	Leeds bed, settled.	Leeds bed, sand-filtered.	Contact bed No. II.	Ducat bed.	Cameron plant.	Whittaker bed, unsettled.	Whittaker bed, sand-filtered.	Leeds bed, unsettled.	Leeds bed, settled.	Leeds bed, sand-filtered.	Contact bed No. II.	Ducat bed.	Cameron plant.	Whittaker bed, unsettled.	Whittaker bed, sand-filtered.	Leeds bed, unsettled.	Leeds bed, settled.	Leeds bed, sand-filtered.	Contact bed No. II.	Ducat bed.	Cameron plant.
January 12	6·6	6·6	6·6	6·6	6·6	6·6	—	—	5·5	6·5	3·0	4·2	5·0	6·5	—	—	5·5	4·0	3·0	4·3	3·5	3·5	—	—
" 19	—	6·5	—	6·5	6·5	—	6·5	—	—	3·0	—	Tr.	Tr.	—	3·0	—	—	2·5	—	2·5	3·0	—	—	—
" 26	—	6·0	—	6·0	6·0	6·0	—	6·0	—	4·0	—	1·0	3·5	4·0	—	1·0	—	1·0	—	2·0	3·0	2·0	—	—
February 2	6·0	6·0	6·0	6·0	6·0	6·0	6·0	6·0	1·5	3·5	0	1·0	5·5	5·0	2·5	2·0	3·5	3·0	Tr.	1·0	1·5	1·5	3·5	Tr.
" 10	—	6·3	—	6·3	6·3	6·3	—	—	—	4·5	—	0	1·5	5·0	—	—	—	2·0	—	1·0	2·0	1·5	—	—
" 18	—	6·3	—	6·3	6·3	—	—	—	—	4·5	—	0	3·5	—	—	—	—	3·0	—	0·0	1·0	—	—	—
" 28	—	6·5	—	—	—	6·5	—	—	—	4·5	—	—	—	4·5	—	—	—	3·0	—	—	—	1·5	—	—
March 4	6·3	6·3	—	—	—	6·3	6·3	6·3	4·8	5·5	—	—	—	5·0	4·5	4·5	5·0	5·0	—	—	—	3·5	—	—
" 10	—	6·0	—	—	—	6·0	—	—	—	5·0	—	—	—	4·3	—	—	—	3·0	—	—	—	2·5	—	—
" 16	—	6·3	—	—	—	—	—	—	—	5·0	—	—	—	—	—	—	—	3·0	—	—	—	—	—	—
" 24	—	6·3	6·3	6·3	6·3	6·3	—	—	—	5·5	5·0	5·0	6·0	5·0	—	—	—	2·5	2·5	3·0	4·5	2·5	—	—
April 1	6·3	6·3	6·3	6·3	6·3	6·3	6·2	6·3	4·5	6·0	3·5	5·3	6·0	5·0	4·5	4·5	3·5	3·5	3·5	4·0	5·0	4·0	4·5	0
" 15	—	6·3	—	6·3	6·3	—	—	—	—	4·5	—	4·0	4·8	—	—	—	—	4·0	—	3·0	4·0	—	—	—
" 21	—	6·3	—	—	—	6·3	—	—	—	3·5	—	—	—	3·2	—	—	—	2·0	—	—	—	1·5	—	—
" 27	—	6·3	—	6·0	6.0	6·0	—	—	—	4·5	—	4·5	4·8	5·0	—	—	—	2·5	—	3·0	4·0	2·0	—	—
May 6	—	6·5	—	6·5	6·5	6·5	—	—	—	5·0	—	5·2	6·0	5·2	—	—	—	3·0	—	2·8	4·8	2·0	—	—
" 12	6·0	6·0	6·0	6·0	6·0	—	6·0	6·0	4·0	5·0	3·8	4·5	4·8	—	4·0	1·5	3·8	3·8	4·2	4·5	5·2	—	5·0	0

Mr. W. H. Harrison.

Question 3a. The standard I suggest is, that an effluent on standing when saturated with air in a filled and tightly-stoppered bottle for 24 hours at the laboratory temperature, should not have more than 50 per cent. of its oxygen in solution taken up. In case of doubt the incubator test should also be considered. My reasons for this standard will be found in the above table.

Question 4. *See* Question 1.

(*B.*) *Effluents which pass into a Drinking Water Stream.*

Question 5. In this case I consider that, in addition to the effluent fulfilling the conditions laid down above, a limiting value should be placed upon albuminoid ammonia value, which should not exceed ·08 parts NH_3 per 100,000.

The free ammonia should also be low, say not more than ·4 parts per 100,000 NH_3, as this value is probably the best test as to the efficiency of the process.

Question 6. In addition to the foregoing standard it should be made compulsory for the effluent from the bacterial processes to pass through plots of land or shallow clinker-dust beds, worked intermittently, *i.e.*, running continuously for, say, 2–4 weeks and resting 12–24 weeks.

The method of passing a filter effluent through a layer, 6 in. in depth, of very fine clinker, has when working satisfactorily, been found to decrease the number of bacteria per cc. very considerably. With an effluent such as comes from a Whittaker Bed, and containing about 10 parts of suspended matter per 100,000, we have found it possible to work such plots continuously for over a month when filtering at the rate of 2,000,000 gallons per acre.

I have no observations to offer which bear upon your last request.

I am,

Yours faithfully,

W. H. Harrison.

F. J. Willis, Esq.

Mr. JOHN HAWORTH, F.I.C., Chemist to the Sheffield Corporation.

August 3rd, 1903.

ANSWERS TO QUESTIONS ON STANDARD FOR SEWAGE EFFLUENTS.

Question 1. Yes, if it be provided that cases where exceptional difficulties in treatment arise, on account of admixtures of trade wastes, etc., receive special consideration, or that the Rivers Board, or authority enforcing the standard, will in such exceptional cases show the possibility of attaining the standard set up at a reasonable cost.

Standard methods of applying the necessary tests should also be laid down.

Question 2. An absolute standard such as that of the Mersey and Irwell Joint Committee and including non-putrescibility and a low rate of absorption of dissolved oxygen from aërated water, would be reasonable and satisfactory.

Experience shows that effluents, conforming to the Mersey and Irwell standards for oxygen absorption in four hours and albuminoid ammonia, usually have a low rate of absorption of dissolved oxygen from aërated water, and are non-putrescible and capable of supporting the life of fish.

Question 3. After experience with two other methods of determining dissolved oxygen in water and sewage effluents, I find that Winkler's method, as modified by Dr. Rideal, is fairly accurate, simple, and the results are obtained most readily.

Question 3a. I should prefer to give an answer to this question at a later date, when I hope to have more data available.

Question 5. A higher standard for effluents entering a stream from which drinking water is obtained should certainly be required. Such effluents should be practically sterile and be submitted to severe bacteriological tests.

I am not aware of any sewage effluent at present which could, with absolute safety, be admitted to a stream from which drinking water is obtained, unless most efficient filtration is resorted to subsequently.

JOHN HAWORTH.

Mr. E. A. LETTS, D.Sc., Ph.D., etc., etc., Professor of Chemistry at Queen's College, Belfast.

In forwarding the following reply, Dr. Letts said, "I cannot help feeling that before standards of the kind I advocate are adopted, further researches are necessary."

Standards for Sewage Effluents.

With regard to :—

(A) *Effluents which pass into a non-drinking-water stream.*

In my opinion a fixed standard of impurity based upon either the absolute proportions of organic carbon and organic nitrogen, or upon these of the albuminoid ammonia and oxygen absorbed from permanganate, by the given effluent, are not to be recommended, because such a standard not only ignores the differences in dilution and consequent oxidation of different effluents which is *the* important point, but also the differences in character and putrescibility of different effluents. It seems to me that any rational standard of impurity must take into account local conditions, and should be based not only on the nature of the particular effluent, but also upon the volume and nature of the water into which it is discharged. For it may be assumed, I think, that fouling only occurs in an effluent or in an effluent diluted with water, when the dissolved oxygen and the nitrates (supposing these latter to be present originally) have disappeared,* and consequently there is always a certain ratio which may be called the "limit of safety" between the volume of sewage effluent which should be permitted to flow into a watercourse, and the volume of water, with which it is there mixed.

Take, for instance, the case of two inland towns of the same size, one situated on a large and the other on a small river.

The thing to be avoided is the fouling of these rivers, and it seems to me to be absurd to compel the town situated on the big river to purify its sewage as highly as the one on the small river. It would, I think, be almost as reasonable to compel all towns situated on the sea coast to purify their sewage to the same extent.

Again, suppose that "non-putrescibility" of the effluent is taken as a standard; the idea is excellent in the case of a large manufacturing district with a stream which is more or less a sewer, but why force this standard upon the town situated on the big river ? Nature has given that town an asset of great pecuniary value in the shape of its river, which is capable of doing most, if not all, of the work in the purification of its sewage. Why should its ratepayers not enjoy that advantage ?

If, then, it be granted that a standard should be fixed, which is based on the one hand on the amount of impurity to be removed or oxidized, and on the other on the available oxygen in the water course to effect this removal, the question arises as to whether there are any simple and reliable analytical processes for determining the oxygen-absorbing power of a given sewage or effluent, and also the "available oxygen" present in the water into which it is to be discharged; that is to say, the dissolved oxygen of the latter *plus* the oxygen of the nitrates, should there be any. As regards the first point, I am aware that most chemists would regard the indications of the permanganate test as sufficient, but certain results which I have obtained are opposed to that view.† Thus in a series of experiments with mixtures of 1 per cent. sewage in sea water, the "oxygen absorbed" test (four hours at 80° Fahr.) gave with the original mixture 0·144 parts of oxygen required per 100,000, whereas the direct determination by gasometric methods showed that 0·46 part had actually been absorbed in 48 hours, *or more than three times as much.* Also on contrasting the differences between the two tests, after corresponding intervals, great discrepancies were found, thus :

	Dissolved Oxygen actually disappearing after.	Differences between the "oxygen absorbed" originally and after.
6 hours	0·0043	0·018
24 ,,	0·2996	0·036
48 ,,	0·4602	0·063

The two columns should, of course, correspond if the oxygen of the permanganate acted in the same way as the dissolved oxygen of the mixture. I therefore think that the indications of the permanganate test are useless for the object in question.

With reference to the second point, the determination of the dissolved oxygen and the "nitric oxygen" (if one may be permitted to use the expression), either in a sewage or water sample, present no special difficulties.

For the first, I have found that my own method,‡ based to some extent on Mohr's original volumetric process, is both accurate and expeditious, the whole process requiring less than half an hour. But probably any of the other volumetric methods would be found sufficiently accurate.

For nitrates, there can be no question that the determination by means of the zinc copper couple is the most accurate and reliable. But on the whole I am inclined to adopt my friend Adeney's

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* Some recent experiments of my own have shown that septic tank effluent will completely decompose nitrates corresponding with as much as 2·5 parts per 100,000 of nitric nitrogen in less than 24 hours.

† "On the Nature and Speed of the Chemical Changes occurring in Mixtures of Sewage and Sea Water." Proceedings Roy. Soc. Dublin [1900], Vol. IX. (N.S.), Part III., No. 24.

‡ "On a Simple and Accurate Method for Estimating the Dissolved Oxygen in Fresh Water, Sea Water, Sewage Effluents, etc." Preceedings Roy. Soc. Dublin [1901], Vol. IX. (N.S.), Part IV., No. 33.

Mr. Letts. views, and in the main his methods also. That is to say, to mix a certain proportion of a particular effluent with the water into which it is to be discharged, then to keep the mixture out of contact with air, and at the end of a specified time to see how much free oxygen still remains.

Three factors are evidently of prime importance in such a method of investigation, viz. :—

1. The extent of the dilution.
2. The time interval after making the mixture.
3. The temperature.

As regards the extent of the dilution, it ought obviously to depend upon the existing conditions at the outfall. Thus if the flow of the stream corresponded with a volume equal to 100 times that of the sewage effluent, a one per cent. mixture should be made, or if it only corresponded with 50 times, a two per cent. mixture, and so on. The time and temperature may be considered together, and here I cannot speak with certainty, but as a suitable temperature enormously "hurries up" most bacterial actions, I should think that a 24 hours' interval would suffice for all practical purposes, if the mixture were placed in an incubator at from 21° Cent.–35° Cent.

[The mixture of effluent and water is conveniently made in a half Winchester quart bottle. The proper volume of effluent being first run on, the water sample should be added by means of a syphon reaching nearly to the bottom of the bottle, in order as far as possible to avoid aëration of the mixture. The bottle, when quite full, is stoppered, without enclosing air bubbles, inverted, and placed on the incubator in a shallow vessel containing water so that the stopper is covered. Adeney determines the dissolved oxygen remaining at the end of the experiment by gasometric methods, as well as the carbonic anhydride produced, but for the particular purpose now under discussion, one of the volumetric processes would be found more expeditious and quite accurate enough.]

It only remains to discuss the "limit of safety," and here I must confess that I have no experience of a practical kind to guide me, and the subject is beset with difficulties.

Thus in the case of a highly-polluted stream, to start with, the amount of dissolved oxygen may be, I imagine, so small that the nitrate of the effluent may have to do most of the work, and therefore a highly oxidized effluent must be insisted on.

I am chiefly hampered in making an estimate by the want of sufficient and reliable data as regards the amount of dissolved oxygen present in different streams, so few observers having apparently paid any attention to this most important matter. I can therefore only make a suggestion of a tentative kind as regards the limit of safety, viz., that it ought to correspond with a residuum of dissolved oxygen of at least 25 per cent. of that contained in fully aërated water—which latter for practical purposes may be taken as 17 cc. (at N.T.P.) per litre, or 10 millegrams.

The standard of purity I would suggest would therefore be somewhat as follows :—

> A sewage effluent may be discharged into a non-drinking-water stream, provided that a sample when mixed with the water of that stream in the proportion corresponding with the average discharge of the former and the average flow of the latter, and kept in a stoppered bottle completely full of the mixture for 24 hours at a temperature of 80° Fahr., shall give a mixture containing at the end of that time not less than 2·5 milligrammes of dissolved oxygen per litre.

I wish to add that before fixing a standard of the above kind, further investigations appear to be necessary : (1) On the most suitable time and temperature for the incubation, and (2) on the amount of dissolved oxygen and nitrates in various streams and rivers.

(B) *Effluents which may pass into a drinking-water stream.*

I certainly consider that a higher standard should be required in regard to effluents entering a stream from which drinking-water is obtained, than of those entering a stream which is not used for that purpose, but I see many difficulties in approaching the question, which, after all, is more of a bacteriological than a chemical nature, as there is no perfectly clear evidence (to the best of my belief) that the sewage matters in an effluent are *per se* injurious to health, while on the other hand there *is* evidence to show that the presence of specific pathogenic organisms in an otherwise pure drinking-water may induce disease.

I am opposed to the use of water for drinking purposes which is known to have received sewage effluent, as a broad principle. Should, however, the employment of such water be practically a necessity—as with the Thames—very stringent precautions should be taken to ensure the maximum of purification of any sewage effluent which may flow into it.

It is questionable whether this maximum can be reached except by finally submitting sewage effluents to a careful system of irrigation with under-drainage, that is to say, to a real filtration. Or, as the alternative to filtration, to an actual sterilization by heat. As regards this latter, I do not think that the cost would be prohibitive, or that the practical difficulties are insurmountable.

Some time ago I brought under Sir William Ramsay's notice a sterilizer used by a firm of aërated water manufacturers in Belfast, based on the regenerative principle. The sterilizer was worked by a single Bunsen's burner, and had an efficiency of, I think, 1,000 gallons a day.

I do not see why the same principle should not be used for sterilizing effluents if a cheaper fuel, such as Mond gas, or even coke, were employed.

MR. F. R. O'SHAUGHNESSY. CHEMIST TO THE BIRMINGHAM, TAME, AND REA DISTRICT DRAINAGE BOARD.

The Laboratory,
Tyburn, Birmingham,
October 1st, 1903.

F. J. Willis, Esq.,
The Secretary,
Royal Commission on Sewage Disposal.

STANDARDS FOR SEWAGE EFFLUENTS.

DEAR SIR,

Please accept my apology for not filling up and sending the answers to the questions in the form dated May, 1903, earlier. The extra work I am doing for the Commission takes up so much of my time that I have not been able to devote my attention to this subject.

My answers are as follows :—

(A) *Effluents which will pass into non-drinking water.*

1. I am in favour of fixed standards.

2. For general purposes I think a standard based on the non-putrescibility of the effluent will be sufficient for most cases.

Other qualities of an effluent, such as the rate of absorption of dissolved oxygen, the exact quantity of organic matter, are partly, at all events dependent on this.

I do not, however, wish it to be inferred that I am against further limits being placed on the quality of the effluent. Quite the contrary. A standard based on arbitrary figures is not so generally applicable as the test of non-putrescibility, and in practice will, in my opinion, call for constant modification on account of special circumstances.

In this respect I may say that I consider the standard referred to in your form, *i.e.*, that of the Mersey and Irwell Joint Committee, is somewhat too stringent for ordinary working purposes. Such a standard I think cannot be maintained at present in everyday work, although in special cases it is occasionally surpassed.

With respect to the question of the rate of absorption of "dissolved oxygen" I wish to state that I am at present making systematic observations of the behaviour of effluents in this respect, but at present I am not prepared to make a statement thereon.

With respect to the question of the quantity of organic matter in an effluent, I think it desirable for practical purposes that some provisional figure or figures be adopted as a maximum limit of impurity for the guidance of engineers, members of committees, etc., such figures being always considered in connection with the special features of the case.

From my experience I would suggest as working figures the following—say for albuminoid nitrogen ·16 parts per 100,000, say for oxygen absorption 2·00 parts per 100,000.

With regard to the effect of an effluent on the bed of a stream I generally find that plant growth takes place most vigorously where the effluent has been well nitrified and well diluted.

The effluent from the farm of the Birmingham Tame and Rea District Drainage Board is roughly about equal in bulk to the average flow of the river into which it discharges. No appreciable growth has been observed by me within 12 miles below the Joint Board's Works, whilst at several points above these works abundant growth takes place in the river bed.

3. At the present time I am not prepared to state my views on this question.

4. I am not opposed to a definite standard.

(B) *Effluents which may pass into a drinking water stream.*

5. I consider that a very much higher standard than the above should be adopted for such cases. As I have not had occasion to give this question any attention in practice, my views thereon are chiefly theoretical. Also as sewage effluents from most methods of treatment contain enormous numbers of micro-organisms, many of which are objectionable, or even dangerous, means should be taken to remove the dangerous forms and generally reduce the number of organisms.

6. I have no grounds for thinking that it is possible to successfully sterilize sewage effluents of appreciable bulk.

I have made no exact experiments as to whether it is easier to treat a small volume of a strong sewage or a larger volume of a weak sewage, the total organic matter being the same. From general observations on the manipulation of bacteria beds, however, I am of opinion that it is much easier to successfully treat the larger bulk of weaker sewage. This opinion is based on the observed difficulty of treating a concentrated sewage on bacteria beds, as against the comparative ease with which a satisfactory effluent may be obtained with a more dilute sewage.

I am, Sir,
Yours faithfully,
F. R. O'SHAUGHNESSY.

Mr. SAMUEL RIDEAL, D.Sc., F.I.C.

QUESTIONS WITH REGARD TO STANDARDS FOR SEWAGE EFFLUENTS.

As I have already published opinions on most of the points mentioned in the circular, I think it will be useful to include in my answers some relevant passages from the various publications.

Question 1. I am not in favour of standards fixed without consideration of local conditions, especially of the volume, aeration and general state of the recipient stream.

" Rideal on Sewage, 1901," p. 15 :—" The conditions for safe discharge into a flowing stream depend upon local factors . . . . such as time, light, volume of oxygen, and various life of a river."

Ibid., p. 45 :—" But in all these arbitrary limits, no account is taken of the volume of the river into which the effluents are discharged . . . . Provided a river is well aerated, or an effluent is well nitrated, or an oxidizing agent is supplied in sufficient quantity at the time of contact, an effluent may contain a larger quantity of organic matter than has been sanctioned in the past, and variations in such quantities are permissible under conditions varied in the above way . . Some fixed distance below the outfall in midstream should be specified as the locality at which samples should be taken."

Ibid. ,p. 46 :—(For reasons given) " an arbitrary standard based upon the albuminoid figure is valueless."

Question 2 (a) *Ibid.*, p. 43.—" This test, though extremely useful, is arbitrary in character, as an effluent is not intended to be stored by itself, but when finished, to be discharged at once into water which is moving and aerated. If an effluent passes the incubator test it can be discharged into a dry ditch without fear of subsequent putrefaction."

Question 2 (b) Useful, but too limited in scope.

Question 2 (c) See an example, *ibid.*, p. 46 (referring to Ribble Joint Board), showing that " an absolute standard," taking in only one or two factors, is inadmissible.

Question 2 (d) I would condemn entirely the second standard mentioned, the " ratio of oxidized to albuminoid nitrogen," because :

1. For the chief reason, it leaves out of consideration the free ammonia, which, especially in strong sewages, enters very largely into the question of nuisance, and also often greatly retards natural bacterial improvement. This fact is implicitly recognised in the Commissioners' next paragraph, " The Commission feel it is important to bear in mind . . . . "
2. The albuminoid figure relates to different kinds of organic matter, having frequently widely differing relations to bacterial change (*ibid.*, p. 47).

On the other hand (" Rideal on Sewage," p. 49), " the proportion between the oxidised and unoxidised nitrogen denotes the extent to which the sample has been purified."

The oxygen-consumed figure has also to be taken into account, not in an isolated manner, but relatively to the other factors. Simple formulæ combining the relations, first suggested to me by Mr. Henry Law, M.I.C.E., I published in 1897 in a lecture at the Society of Arts (*J. Soc. Arts*, Dec. 17th, 1897), and further explained in my above-mentioned work on Sewage (p. 16), as follows : " Where X is the flow of the stream, O the amount of dissolved oxygen, S the volume of effluent, M the " oxygen consumed " by the latter, N the available oxygen as nitrate and nitrite, C the ratio between the amount of oxygen in the stream and that which is required to oxidize the organic matter in the effluent, then the equivalent of minimum safety will be —

$$X\,O = C\,(M - N)\,S.$$

Where the sewage is fresh, and no nitrates have been formed

$$X\,O = C\,M\,S.$$

If N be less than M, $M - N =$ the deficit of oxygen in the effluent, requiring to be supplemented by the free oxygen in the river ; such an effluent will throw a burden on the river, and cannot be considered in a satisfactory state, and it will be a question of volume and other circumstances whether it can be permitted to be discharged at all. This may be determined by the consideration that if the available oxygen of the river, X O, be greater than the demand $(M - N)$ S, there will be a chance of the stream dealing with the inflowing liquid, but if the reverse be the case, foulness will necessarily accrue.

In the favourable cases where bacteria and algæ are active, and the oxygen of the river is able, by their help, to deal rapidly with the incoming residues, the minimum ratio between the volume of the stream and the volume of effluent that could be allowed to be discharged into it would be indicated by the value of C in the above equation, which would also approximately denote how far the population might increase before the proportion could be seriously disturbed. The minimum figure will be reduced by the nitrites or nitrates of the river water itself, or the free oxygen which may be present in the effluent." These figures are supplemental to the O and the N of the above equation, but are better left as a margin of safety.

Question 3. Rideal, " Aeration Test for Sewage Effluents," *Analyst*, August, 1901 :—" Many outdoor circumstances, such as space and time, soil, life, flow and wind, cannot be imitated in the laboratory, so that the test so applied must always to some extent be an artificial one."

Especially is this the case with the closed test, because (*ibid.*, p. 198) "the dissolved oxygen in saturated water only amounts to one part by weight in 100,000, so could not be sufficient to oxidize the organic matter of mixed liquids which, exposed to the air, would rapidly improve." A typical example follows in the paper.

A closed test in the dark, as conducted systematically by Albert Levy in Paris, only regards a section even of the bacteria and does not relate to natural conditions.

Question 3A. The test of allowing mixtures of equal volumes of the effluent and of fully-aerated water to stand in open vessels, and to determine the dissolved oxygen at 12, 24, and 48 hours, is very useful. Dibdin's stipulation that the amount should not fall below 50 per cent. of saturation at the temperature (founded on his observation that " whenever the aeration of the water of the Thames was found to exceed this minimum there was no suggestion of nuisance ") is a reasonable one, but in his proposal of " equal widths and depths," without a definite size being given (*Journal Soc. Chem. Industry*, June, 1900, p. 498) the ratio of surface to volume varies in each case. I have examined the subject in the paper mentioned in answer to Question 3, and find that the best conditions for carrying out the test uniformly are, " the samples should be kept at a uniform temperature in cylinders 6in. deep and 3 in. wide, exposed to air and light, but protected from dust. The volume will be about 600 cc., and the ratio of surface to volume 1 to 6. . . . This ratio is the most important point to keep constant, as it regulates the rate of absorption of oxygen from the atmosphere.

Question 4. See answer to Question 1.

Question 5. Not a higher standard, as water which has received effluents is not in a different position from ordinary river water in requiring to be subsequently specially purified if it is to be used, which I deprecate, for drinking purposes.

Question 6. I do not consider it generally possible, from conditions of expense, to sterilise the whole of sewage effluents. But I have indicated (Rideal's Sewage, p. 69) how they can in special cases, as in those from hospitals, be " finished " by chemical agents. Some such process as the Liernur is also available on a limited scale (*ibid.*, p. 166).

With reference to the next paragraph, in Local Government Board inquiries the state of the stream has always been taken into account as almost a dominating feature. Such a stream as is alluded to would be considerably *improved* by the addition of a clear and properly nitrated effluent. The formula I have given above would deal with the question.

In answer to the last paragraph, I have found that, provided they are applied in such volume and in such a manner as to allow proper aeration for the filters or land, strong sewages not containing excessive amounts of free ammonia (or extraneous ingredients of trade origin), are as easy to treat bacterially as weak ones.

June 4th, 1903. SAMUEL RIDEAL.

Mr. H. ALFRED ROECHLING, M.I.C.E., Etc., Etc.

Standards for Sewage Effluents.

Circular dated May, 190

Preliminary Observations.

The circular of May, 1903, deals practically only with sewage pollution, and is silent on the question of micro-organisms and mineral pollution; but liberty has been taken to assume in the following remarks that these matters ought not to be left out of consideration in settling the question of standards for sewage effluents.

It is further not clear from the circular whether the division of streams into drinking-water and non-drinking-water streams has only been assumed for the purposes of the report, or whether it is intended to recommend the application of this division to streams and watersheds for rivers pollution purposes; but the following observations are based on the supposition that such recommendation is intended.

The circular points out that the condition of the stream which takes the effluent cannot be taken into account when considering the question of rivers pollution, but in this place it has been assumed that this limitation refers solely to the quality of the water in a given stream, and not to its quantity; otherwise, and without any further considerations, a "universal absolute standard" would be the logical sequence.

Finally, it is necessary to state that in considering the question of standards for sewage effluents it has been assumed that in future the waste liquors from manufactories will in the majority of cases be treated together with domestic sewage by the local or sanitary authorities of the district, as has been recommended.

Division of Streams into Non-drinking and Drinking-water Streams.

Whilst admitting that for purely theoretical purposes it may seem convenient to divide all streams into drinking-water and non-drinking-water streams, I am against applying such a division to the practical work of rivers pollution, as it will be quite impossible to adhere to it in practice, and there are further strong objections to such a division from economic and equitable grounds.

It might be urged that without such a division the new central authority would be considerably hampered through the want of discretionary powers in dealing with all the various cases that will come before it; but in my judgment, whereas an Act of Parliament must necessarily be more or less rigid, the requisite elasticity can be imparted to the central authority by empowering it to issue rules and by-laws on various subjects.

Dealing first with the practical objections to such a division, and assuming that the new central authority were to have power to make a formal declaration of legal effect for this purpose, the question immediately arises, how many human beings would have to be proved to be in the habit of drinking the water of a stream before such declaration could be made?

Further, it must be borne in mind that, as the whole population of this country can never be supplied with water entirely from underground sources, surface-derived waters must always remain amongst the sources of our water supplies. Indeed, it is quite probable that with the rapid increase of population surface sources may in future have to be relied on in even a greater degree than heretofore, so that nothing should be done which may irrevocably stamp some streams as non-drinking-water streams.

There are a large number of streams in this country which are used near their sources for water-supply purposes, and there are others, such as the Thames, which are used for this purpose near their mouths. What is to be done in their case? Are they wholly to be treated as drinking-water streams, or partly as drinking-water and partly as non-drinking-water streams? Where is to be the boundary between drinking-water and non-drinking-water zones and areas of rivers and watersheds?

What is to be done with the prescriptive rights of sewage purification works that may have been acquired in the case of non-drinking-water streams when either temporarily during drought or permanently after careful purification, it becomes necessary to utilise the water again for drinking purposes?

Coming now to the objections to such a division on economic and equitable grounds, could it not be urged that the setting up of differential treatment of areas in an Act of Parliament, which would practically be equivalent to preferential treatment, is very undesirable, and might establish a very doubtful and awkward precedent? Why should some areas be declared by law to be in a better position as to sewage treatment than others? Why should some be compelled to do little, others much, in this respect? Might it not happen that the small and poor communities in the upper reaches of a river, where its water is drunk, would have to purify their sewage at considerable expense, whereas the large and rich communities lower down escaped with proportionately little expense?

Are the uses of river water for bathing, cattle drinking, and manufacturing purposes to be declared illegal at the time a stream is declared a non-drinking-water stream, so that no damages can be claimed against those who render the water unfit for such uses?

One is therefore driven to the conclusion that the law ought not to recognise any main division of streams into drinking-water and non-drinking-water streams, but that all streams ought to be treated alike, with liberty of discretion to the central authority to make such differences on minor points as they may deem fair and reasonable.

Standards of Purity.

Standards of purity may be divided according to the area of their application into "local" and "universal," and according to their nature into "relative" and "absolute" standards.

If it is necessary to purify sewage at all, it is essential—and I think this is now fully recognised by all—to remove therefrom its most poisonous substances, namely, the pathogenic micro-organisms, no matter how large or how small the river is, so that we have to deal here with a universal absolute standard.

Dealing next with the dead organic matters, either in suspension or solution, I am satisfied that from a purely scientific point of view we ought to adopt local relative standards depending on the digestive, carrying, and other capacities of the river water which takes an effluent. But this would mean, if carried to its logical conclusions, that the standards of purity would vary for every river, for every point of one and the same river, and for every season, a so perplexing and exceedingly complicated multiplicity of standards as to be out of the question for practical purposes, where simple and easy rules are of paramount importance.

It is necessary, therefore, to adopt for this purpose likewise a universal absolute standard.

Considering further the effect of the mineral matters contained in an effluent, some require to be judged by universal absolute standards, others by somewhat local relative standards, so that here we have to deal with a combination of the two.

It will be clear, therefore, that the general standard for sewage effluents will be a combination of universal absolute with local relative standards, and the standards I would recommend are :—

I. *As to micro-organisms in effluent water.*

1. The effluent shall be free from pathogenic micro-organisms.

II. *As to dead organic matters in effluent water.*

1. The effluent shall be free from putrescible matters.

III. *As to mineral matters in effluent water.*

1. The effluent shall not contain mineral matters that can discolour the water or impart to it a disagreeable smell.
2. The effluent shall not contain mineral matters that can injuriously act upon the flora or fauna of the river water.
3. The effluent shall be free from mineral matters to such an extent that they do not give rise to luxurious growth in the river water.

IV. *As to dead organic and mineral matters together.*

1. The effluent shall be free from all matters that will prejudicially affect the flow of the river.

I am inclined to think it would be comparatively a simple matter to apply tests to ascertain whether a particular effluent complies with these standards or not, especially if power be given to the new central authority to prescribe, vary, or cancel from time to time the regulation tests necessary for this purpose.

To ascertain whether an effluent contains disease-exciting causes, the new central authority might, under ordinary conditions of health, be satisfied with a determination of the total number of micro-organisms, or of one particular kind, in one cubic centimetre of effluent, but should have power to insist upon a more careful bacteriological examination for the detection of pathogenic forms when the state of the public health of a district requires it. For this purpose the central authority should have power to order any sanitary or local authority to supply them with weekly, monthly, quarterly, or yearly health returns

Sterilisation of Sewage Effluents.

Concerning the question of sterilising sewage by artificial means, I would point out that for all practical purposes the passing of sewage through suitable land on a well-managed sewage farm has sufficed up to now to deprive it of its pathogenic micro-organisms, and in proof of this I would mention that there is no case on record, so far as I know, where the effluent from a well-managed sewage farm has caused an outbreak of typhoid fever. The method is not an absolute guarantee for such removal, just as little as an artificial process of sterilisation would be an absolute guarantee; both methods are subject to a number of errors, depending partly on human agencies, which will never be completely effaced; but so far the method of land treatment affords the only practicable, reasonable, and well-tried method for such removal.

25th June, 1903. H. ALFRED ROECHLING.

Mr. FRANK SCUDDER, F.C.S., F.I.C.

(*First Letter.*)

14, Mosley Street,
Manchester.
June 30th, 1903.

DEAR SIR,

Re STANDARDS FOR SEWAGE EFFLUENTS.

A. Effluents which will pass into a Non-drinking Water Stream.

In reply to your circular letter dated May, 1903, I have the pleasure in stating my views on the questions asked as follows :—

I am not in favour of "fixed," "absolute," or "definite" numerical standards of purity.

The provisional standards which were adopted some years ago for carrying out the work of the Mersey and Irwell Joint Committee were as follows :—

Limits of Impurity Allowable.

	Grains per gallon.
1. Oxygen absorbed from an acid solution of permanganate of potash acting upon the sewage effluent for three minutes at 60° Fahr.	0·25
2. Ditto, four hours' test at 60° Fahr.	1·00
3. Albuminoid ammonia	0·10

These standards are used for the purpose of classifying sewage effluents, the main object being to differentiate effluents of a putrescible character from those that are non-putrescible.

They ought not to be referred to as absolute standards because they do not give you all the information that is required to enable one to draw an accurate deduction in every instance. If an absolute standard is to be fixed regard must also be had to the rate at which dissolved oxygen is removed from surrounding water. I have already pointed out to the Commission, at Question 6098*, that mere dilution of crude sewage with water so as to bring it within the provisional standards of the Mersey and Irwell Board does not produce a non-putrescible effluent. An effluent so produced is still capable of robbing aërated water of its dissolved oxygen. A standard, therefore, which is based entirely on the quality of the organic matter remaining in an effluent as measured by the permanganate test, and the albuminoid ammonia test, may indicate a quality of organic matter having a less tendency to rob aërated water of its dissolved oxygen than an effluent derived from the direct dilution of crude sewage, both effluents having the same numerical figures of oxygen absorbed from permanganate and of albuminoid ammonia. Conversely a sewage effluent may be incapable of robbing aërated water of its dissolved oxygen and will yield numerical figures of oxygen absorbed from permanganate and of albuminoid ammonia, which infringe the provisional standards referred to.

The Commission refer in their circular letter to the "residual organic matter" in an effluent being less fermentible than the "same weight of organic matter" remaining in an effluent which is derived from a weak sewage. This is, in my opinion, rather an ambiguous statement to make, because in the first place there is no correct method of analysis which can accurately determine the weight of organic matter in a sewage effluent, and secondly, the standards based on the permanganate test, and on the yield of albuminoid ammonia, only indicate quality and not the weight of organic matter. Even the determination of the organic nitrogen either by Kjeldahl or any other method does not give you any accurate determination of the weight of organic matter in an effluent—the factor for multiplying the nitrogen figure found being different for each organic substance present, and in organic substances free from nitrogen of no value at all.

In answer to Question 2. I am not in favour of standard (*a*). A standard based solely on the non-putrescibility of an effluent upon incubation without reference to any other tests is not sufficient to form an accurate judgment of the quality of all sewage effluents. The incubator test was introduced into the work of the Joint Committee for the purpose of differentiating tank effluents from filtered effluents, there being an expression of opinion amongst sanitary authorities that if they provided efficient tank treatment they ought not in addition to provide for filtration of sewage. The incubator test is not a severe enough test to apply to a filtered effluent, and alone is not sufficiently reliable.

With regard to standard (*b*) it is preferable to the previous standard (*a*), but it does not go far enough, and is not sufficient to form an accurate judgment on all sewage effluents, especially in sewages containing trade waste. (*See* analyses of filtered sewage effluents from the Manchester Sewage Works, Table 4.) The presence of germicidal substances interfere with the test. (*See* Minutes of Evidence, Question 6108.)*

With regard to standard (*c*), which is the provisional one of the Mersey and Irwell Joint Committee, it is important to bear in mind that three tests have to be fulfilled to meet the standard. If the sewage effluent complies with all three tests it is invariably of a non-putrescible character, because the three minutes permanganate test, viz., 0·25 grain oxygen absorbed per gallon, is a severe one to comply with. By this I do not mean to insinuate that it is difficult to obtain in practice. On the contrary, out of 456 samples of sewage effluents recently examined, 236 did not infringe the standard. These effluents would bear the most stringent examination. The second test which is applied is the four hours permanganate test, and the limit of impurity allowable in a sewage effluent is fixed at one grain oxygen absorbed per gallon. Out of the 456 samples examined 311 samples complied with the standard.

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* Interim Report, Royal Commission on Sewage Disposal, Vol. II.

However, this test does admit of a few instances of effluents of a putrescible character creeping in, and it is also open to the objection already referred to, viz., dilution of crude sewage so as to meet the standard, and yet containing putrescible organic matter. Any definite standard must therefore provide for such cases, and I will deal with this point later on. The third test which is applied is the albuminoid ammonia test, and the limit of impurity allowable is fixed at 0·1 grain ammonia per gallon.

This is the least satisfactory of the three tests, and experience corroborates this statement Results are still, however, being recorded, because until a complete explanation is forthcoming why in effluents of a non-putrescible character the albuminoid ammonia figure infringes the standard its true value cannot be ascertained. Suspended matter has generally accounted for this feature, but many samples of a clear and sparkling character have an albuminoid figure higher than 0·1.

With regard to standard (*d*) I am of opinion that it is of little value, inasmuch as many effluents of a non-putrescible character are free from nitric nitrogen. (*See* Vol. III., Appendices, p. 261, Appendix No. 6, Table A.* Minutes of Evidence p. 209. Tables 7, 8 and 9.†)

My experience is that it is more reliable to test the power of a sewage effluent to destroy nitrates, and to ascertain the rate at which nitrates disappear in the effluents.

Before numerical standards are further discussed it would be well to point out what tests are necessary in my opinion to enable an accurate deduction being made as to the character of a sewage effluent. The tests that I rely upon are as follows :—

1. Permanganate test ; three minutes test.
2. Permanganate test, four hours test.
3. Albuminoid ammonia.
4. Rate at which dissolved oxygen is destroyed when the effluent is presented to aërated water :—
    - (*a*) After 24 hours at 75° Fahr.
    - (*b*) After 48 hours at 75° Fahr.
5. Nitrites.
6. Nitrates, and the power of the effluent to destroy nitrates acting at 75° F. for 48 hours.
7. Chlorine.

In all important cases, and when the history of the sewage effluent is unknown, this information ought to be the basis upon which to form an opinion.

When the provisional standard of the Mersey and Irwell Joint Committee, involving as it does the application of three tests, is strengthened by the addition of two others, viz., first the rate at which dissolved oxygen is destroyed when the effluent is presented to aërated water, and secondly, the rate at which nitrates disappear when the effluent is incubated at 75° Fahr. for 48 hours, a more reliable working standard is obtained.

With regard to the dissolved oxygen test, the sewage effluent ought not to absorb more than two grains of dissolved oxygen per gallon of sewage effluent in 48 hours at 75° Fahr. (test to be carried out as directed by adding one volume of sewage effluent to nine volumes of tap water).

In the nitrate test the sewage effluent ought not to destroy more than 0·25 grain nitric nitrogen per gallon during a period of incubation of 48 hours at 75° Fahr.

This modification of the Mersey and Irwell standard is only of value for the purpose of more accurately classifying sewage effluents and must not be looked upon as an "absolute" numerical standard. If you refer to the results of my analyses given in Appendix No. 6, pages 261 and 262,* and to Table 2 herewith sent it will be observed that many of the sewage effluents comply with the numerical standards, and in some cases are much lower than the limits of impurity allowable.

In answer to Question 3, I enclose you a description of the test, and photographs of the apparatus which I have used for a long time for the determination of dissolved oxygen. As regards accuracy, simplicity, and manipulation it is all that can be desired.

With reference to effluents which may pass into a drinking water stream, I am preparing a statement which will be sent you early next week.

I am, yours truly,
FRANK SCUDDER.

The Secretary of the Royal Commission on Sewage Disposal.

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* Interim Report, Royal Commission on Sewage Disposal, Vol. III.
† " " " " " " Vol. II.

Mr. F. Scudder.

Enclosure I. to Mr. Frank Scudder's Reply.

TABLE 1.

ANALYSES OF SAMPLES OF SEWAGE EFFLUENTS, from Salford Sewage Works.

State of Weather.	Date.	Time.	Method of Purification.	Remarks on Sample as received.	Chemical results expressed in grains per gallon.					
					Ammonias.		Oxygen absorbed.		Chlorides as (Cl.).	Nitrates and Nitrites as (N).
					Free and Saline.	Albuminoid.	3 minutes test.	4 hours test.		
	1902.									
Fine - -	June 17th -	11 a.m.	Tanks - -	Light brown, turbid, small amount of sediment, sewage smell - -	2·52	0·286	0·80	2·56	10·4	0·078
Hot - -	July 15th -	4 p.m. -	Tanks - -	Light brown, turbid with brown sediment, sewage smell - - - - -	2·17	0·450	2·84	5·59	15·5	—
Showery -	October 22nd -	12 noon	Tanks - -	Brown, turbid, with brown sediment, sewage smell - - - - - -	1·26	0·294	1·38	3·35	7·6	—
Rain - -	November 12th	1.30 p.m.	Tanks - -	Brown, turbid, with brown sediment, sewage smell - - - - - -	1·58	0·378	2·35	5·20	10·2	—
Wet - -	December 17th	1.45 p.m.	Tanks - -	Brown, turbid, with brown sediment, sewage smell - - - - - -	1·19	0·291	1·80	4·10	11·3	—
	1903.									
After rain -	January 7th -	3.40 p.m.	Tanks - -	Light brown, with brown sediment, sewage smell - - - - - -	0·98	0·224	1·00	2·60	8·0	—
Fine - -	February 18th	12.45 p.m.	Tanks - -	Almost clear, little grey sediment, lime effluent smell - - - -	1·33	0·210	0·75	2·92	10·4	—
Fine - -	March 25th -	9.35 a.m.	Tanks - -	Brown, turbid, trace of sediment, neutral, sewage smell - - - -	1·68	0·336	2·24	5·01	11·5	0·19

FRANK SCUDDER, F.I.C.,
44, Mosley Street, Manchester

TABLE 2.

ANALYSES OF SAMPLES OF SEWAGE EFFLUENTS, from Salford Sewage Works.

State of Weather.	Date.	Time.	Method of Purification.	Remarks on Sample as Received.	Chemical results expressed in grains per gallon.									
					Ammonias.		Oxygen absorbed.		Chlorides as (CL)	Nitrates and Nitrites as (N)	Dissolved Oxygen test.			
					Free and Saline.	Albuminoid.	3 minutes test.	4 hours test.			Oxygen at start.	Oxygen after 24 hours at 75° Fahr.	Oxygen after 48 hours at 75° Fahr.	Grains Oxygen Consumed after 48 hours
	1902.													
Fine	June 17th	10.30 a.m.	Tanks and filters	Clear and colourless, brown sediment, no smell	0·308	0·170	0·38	0·86	13·5	0·369				
Hot weather	July 15th	4.30 p.m.	Tanks and filters	Clear and colourless, traces of sediment, no smell	0·196	0·060	0·26	0·60	13·6	1·64	5·3	5·3	5·3	0·0
Showery	Aug. 12th	12.15 p.m.	Tanks and filters	Clear and sparkling, traces of sediment, no smell	0·308	0.078	0·17	0·33	10·6	0·738	5·5	5·4	5·2	0·3
Fine	Sept. 18th	11.45 a.m.	Tanks and filters	Clear and colourless, traces of sediment, no smell	0·462	0·103	0·26	0·98	10·0	1·27	6·9	6·4	6·1	0·8
Showery	Oct. 22nd	12.30 p.m.	Tanks and filters	Clear and colourless, no sediment, no smell	0·350	0·117	0·15	0·47	11·0	0·80	6·2	6·1	6·1	0·1
Fine, wet previous days	Dec. 17th	2.30 p.m.	Tanks and filters	Clear and colourless, traces of sediment, no smell	0·294	0·056	0·09	0·18	8·0	1·04	7·4	7·1	6·7	0·7
	1903.													
Heavy rain	Jan. 6th	11.45 a.m.	Tanks and filters	Clear and colourless, light brown sediment, no smell	0·63	0·103	0·21	0·38	7·9	1·20	7·4	7·2	6·7	0·7
After rain	Jan. 7th	4.15 a.m.	Tanks and filters	Clear and colourless, traces of sediment, no smell	0·56	0·091	0·18	0·68	7·7	0·307	7·6	6·8	6·6	1·0
Fine	Jan. 8th	8.35 a.m.	Tanks and filters	Clear and colourless, traces of sediment, no smell	0·56	0·081	0·16	0·54	7·4	0·348	7·6	7·3	6·6	1·0
Fine	Feb. 19th	8. 0 a.m.	Tanks and filters	Clear and colourless, no sediment, no smell	0·17	0·049	0·15	0·38	11·6	1·64	7·3	—	7·2	0·1
Fine	Mar. 25th	10.15 a.m.	Tanks and filters	Clear and colourless, traces of sediment, faint earthy smell	0·28	0·105	0·25	0·60	10·7	1·55	6·6	6·5	6·3	0·3
Fine	April 21st	10.15 a.m.	Tanks and filters	Clear and colourless, no sediment, no smell	0·73	0·088	0·31	0·63	12·3	0·93	7·5	6·6	6·0	1·5
Fine	May 19th	10.30 a.m.	Tanks and filters	Clear and colourless, traces of sediment, faint earthy smell	0·52	0·140	0·25	0·58	9·6	0·63	7·1	6·6	6·3	0·8

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Mr. F. Scudder.

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TABLE 3.

Analyses of Samples of Sewage Effluents, from Manchester Corporation Sewage Works.

State of Weather.	Date.	Time.	Method of Purification.	Remarks on Sample as received.	Chemical results expressed in grains per gallon.					
					Ammonias.		Oxygen absorbed.		Chlorides as (Cl.).	Nitrates and Nitrites as (N).
					Free and Saline.	Albuminoid	3 minutes test.	4 hours test.		
	1902.									
Fine - -	June 17th -	3.10 p.m.	Tanks - -	Brown, turbid, brown sediment, tarry smell - - - - - -	2·59	0·338	2·39	6·12	12·5	0·475
Hot weather	July 15th -	2.0 p.m.	Tanks - -	Light brown, turbid, with dark brown sediment, tarry smell - - -	2·73	0·375	4·2	7·8	13·7	—
Showery -	October 22nd -	3.30 p.m.	Tanks - -	Brown, turbid, with brown sediment, tarry smell - - - - -	1·54	0·313	2·13	4·18	10·9	—
Fine - -	November 12th	4.40 p.m.	Tanks - -	Brown, turbid, with brown sediment, tarry smell - - - - -	2·59	0·495	3·29	6·22	15·0	0·262
Dry - -	December 10th	4.45 p.m.	Tanks - -	Brown, turbid, with brown sediment, tarry smell - - - - -	2·52	0·380	3·14	5·93	18·3	—
	1903.									
Frosty -	January 14th -	12.20 p.m.	Tanks - -	Brown, slightly turbid, with brown sediment, tarry smell - - -	1·47	0·268	2·68	4·96	13·0	—
Fine - -	February 18th	4.15 p.m.	Tanks - -	Brown, slightly turbid, with brown sediment, tarry smell - - -	2·73	0·403	3·72	6·70	15·2	—
Fine - -	March 24th -	2.30 p.m.	Tanks - -	Brown, turbid, with dark brown sediment, tarry smell - - - -	2·10	0·347	3·23	6·17	13·8	0·17
Fine - -	April 21st -	3.0 p.m.	Tanks - -	Brown, turbid, trace of brown sediment, tarry smell - - - -	1·82	0·302	3·39	5·76	12·7	0·24
Fine -	May 19th -	3.45 p.m.	Tanks - -	Brown, turbid, trace of brown sediment, tarry smell - - - -	1·40	0·257	1·34	2·83	11·1	0·25

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TABLE 4.—ANALYSES OF SAMPLES OF SEWAGE EFFLUENTS, from Manchester Corporation Sewage Works.

State of Weather.	Date.	Time.	Method of Purification.	Remarks on Sample as received.	Chemical results expressed in grains per gallon. Ammonias.		Oxygen absorbed.				Dissolved Oxygen Test.			
					Free and Saline.	Albuminoid.	3 minutes Test.	4 hours Test.	Chlorine as (Cl.)	Nitrates and Nitrites as (N.)	Oxygen at start.	Oxygen after 24 hours at 75° Fahr.	Oxygen after 48 hours at 75° Fahr.	Grains of Oxygen Consumed after 48 hours.
	1902.													
Fine	June 17th	3.0 p.m.	Tanks and filters	Brown, slightly turbid, brown sediment, faint smell	0·728	0·184	1·30	2·40	14·0	0·065	—	—	—	—
Fine	August 12th	2.30 p.m.	Tanks and filters	Light brown, turbid, traces of sediment, no smell	1·36	0·189	0·66	1·48	12·1	0·20	5·40	4·60	3·90	1·5
Fine	September 8th	4.35 p.m.	Bacteria beds	Brown, with brown sediment, no smell	1·33	0·115	0·27	0·92	12·7	0·533	6·4	6·1	5·5	0·9
Fine	September 8th	5.0 p.m.	Storm filters	Turbid, with light brown sediment, slight smell	2·10	0·154	0·44	1·47	10·6	0·135	6·2	4·6	4·1	2·1
Showery	October 22nd	3.20 p.m.	Tanks and filters	Light brown, with brown sediment, no smell	1·05	0·096	0.44	0·93	12·0	0·90	6·2	5·9	5·9	0·3
Fine	November 12th	4.55 p.m.	Tanks and filters	Almost colourless, light brown sediment, no smell	1·29	0·187	0·52	1·28	12·1	0·51	7·7	7·6	6·1	1·6
Fine	November 12th	5.0 p.m.	Tanks and storm filters	Almost colourless, traces of sediment, no smell	1·26	0·189	0·83	1·51	12·3	0·53	7·7	7·6	6·9	0·8
Dry	December 10th	4.55 p.m.	Tanks and filters	Light brown, turbid, brown sediment, faint smell	1·92	0·212	1·22	2·16	14·7	0·24	7·3	5·9	4·7	2·6
Dry	December 10th	5.15 p.m.	Tanks and storm filters	Clear and colourless, no sediment, no smell	0·665	0·057	0·28	0·57	13·4	0·82	7·3	6·6	5·9	1·4
	1903.													
Frosty	January 14th	12.20 p.m.	Tanks and filters	Brown, turbid, brown sediment, faint smell	1·82	0·215	1·30	2·75	13·6	0·16	7·9	6·5	4·5	3·4
Fine	January 21st	4.30 p.m.	Tanks and storm filters	Light brown, no sediment, no smell	0·70	0·066	0·54	1·00	14·2	0·817	8·4	7·7	6·5	1·9
Fine	February 18th	4.20 p.m.	Tanks and filters	Slightly turbid, no sediment, slight smell	1·26	0·097	0·73	1·48	13·4	0·58	7·3	—	5·4	1·9
Fine	February 18th	5.0 p.m.	Tanks and storm filters	Clear and colourless, no sediment, no smell	0·52	0·063	0·44	0·92	13·6	0·96	7·3	—	7·1	0·2
Fine	March 24th	1.40 p.m.	Tanks and filters	Brown, turbid, trace of dark brown sediment, tarry smell	1·26	0·169	1·10	1·91	12·6	0·26	6·6	5·7	5·1	1·5
Fine	March 24th	2.20 p.m.	Tanks and storm filters	Clear and colourless, no sediment, no smell	0·73	0·055	0·28	0·68	10·9	0·85	6·6	6·5	5·7	0·9
Fine	April 21st	2.0 p.m.	Tanks and filters	Slightly turbid, grey sediment, slight smell	1·71	0·177	0·65	1·19	12·2	0·32	7·5	6·4	5·7	1·8
Fine	May 19th	2.15 p.m.	Tanks and filters	Faint brown colour, turbid, trace of dark sediment, earthy smell	1·42	0·245	0·79	1·70	9·9	0·11	7·1	6·0	3·7	3·4
Fine	May 19th	3.35 p.m.	Tanks and filters	Faint brown, turbid, little black sediment, slight smell	1·82	0·337	1·37	2·66	10·5	0·07	7·1	5·1	0·3	6·8

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Mr. F. Scudder.

Enclosure II. to Mr. Frank Scudder's Reply.

Dissolved Oxygen Test.

The reagents employed are as follows :—

(1.) Indigo solution. Take 3 grammes of indigo carmine, dissolve in hot water, and make up to one litre.

(2.) Sodium hyposulphite ($NaHSO_2$). Sulphurous acid (SO_2) gas is passed through a saturated solution of carbonate of soda, until saturated with SO_2. 50 cc. of the bisulphite solution is placed in a 6 oz. stoppered bottle, and 10 grammes of zinc dust added, and shaken well for two minutes, keeping the liquid cool by holding under running water. Then fill the bottle with water, and allow to stand 15 minutes, when the top liquid can be decanted into a half Winchester bottle which is at once filled with tap water. Some operators now add milk of lime, and form a neutral hyposulphite of lime, but I prefer to use the liquid without the addition of lime. From this stock solution, a dilute hypo solution is made up to such a strength that 15 to 20 cc. will decolorise 25 cc. of the Indigo solution.

In order to keep the stock hypo for a month, it is advisable to cover the liquid with a layer of petroleum, or to turn the bottle neck downwards in a vessel of water.

Method of procedure.—100 cc. of the sewage effluent are added to 900 cc. tap-water in a half Winchester bottle, well shaken, and allowed to stand half an hour to allow small air bubbles to rise to the surface. The temperature of the liquid is noted. Two 10 oz. stoppered bottles are then filled with the diluted effluent, and placed in the incubator at 75° Fahr. The dissolved oxygen is estimated at start, after 24 hours, and after 48 hours.

Calculation :

emperature 22° C.

1 litre of aerated distilled water at 22° C. contains 6·04 cc. oxygen per litre.
25 cc. Indigo solution = 19·8 cc. hypo solution.
100 cc. Dis. Aq. at 22° C. = 7·7 cc. hypo solution.
$\therefore$ ·604 ÷ 7·7 = 0·0784 cc. oxygen the value of 1 cc. hypo.
but 25 cc. Indigo = 19·8 cc. hypo.

$$\therefore \frac{\cdot 0784 \times 19\cdot 8}{25} = 0\cdot 0621$$ = value of 1 cc. Indigo in terms of oxygen.

25 cc. Indigo = 22·0 cc. hypo.
100 cc. diluted effluent = 9·5 cc. hypo.
but 1 cc. Indigo = 0·0621 cc. oxygen.

$$\therefore \frac{\cdot 0621 \times 25}{22} = 0\cdot 0705$$ = oxygen value of 1 cc. hypo for the day.

and 0·0705 × 9·5 × 10 = 6·70 cc.'s oxygen per litre in the effluent examined.

100 cc. of the original sewage effluent is presented to 6·7 cc.'s dissolved oxygen.
1 cc. oxygen weighs 0·022123 grain.
6·7 × 10 × 4·543 × ·022 = 6·7 grains dissolved oxygen per gallon of sewage effluent.

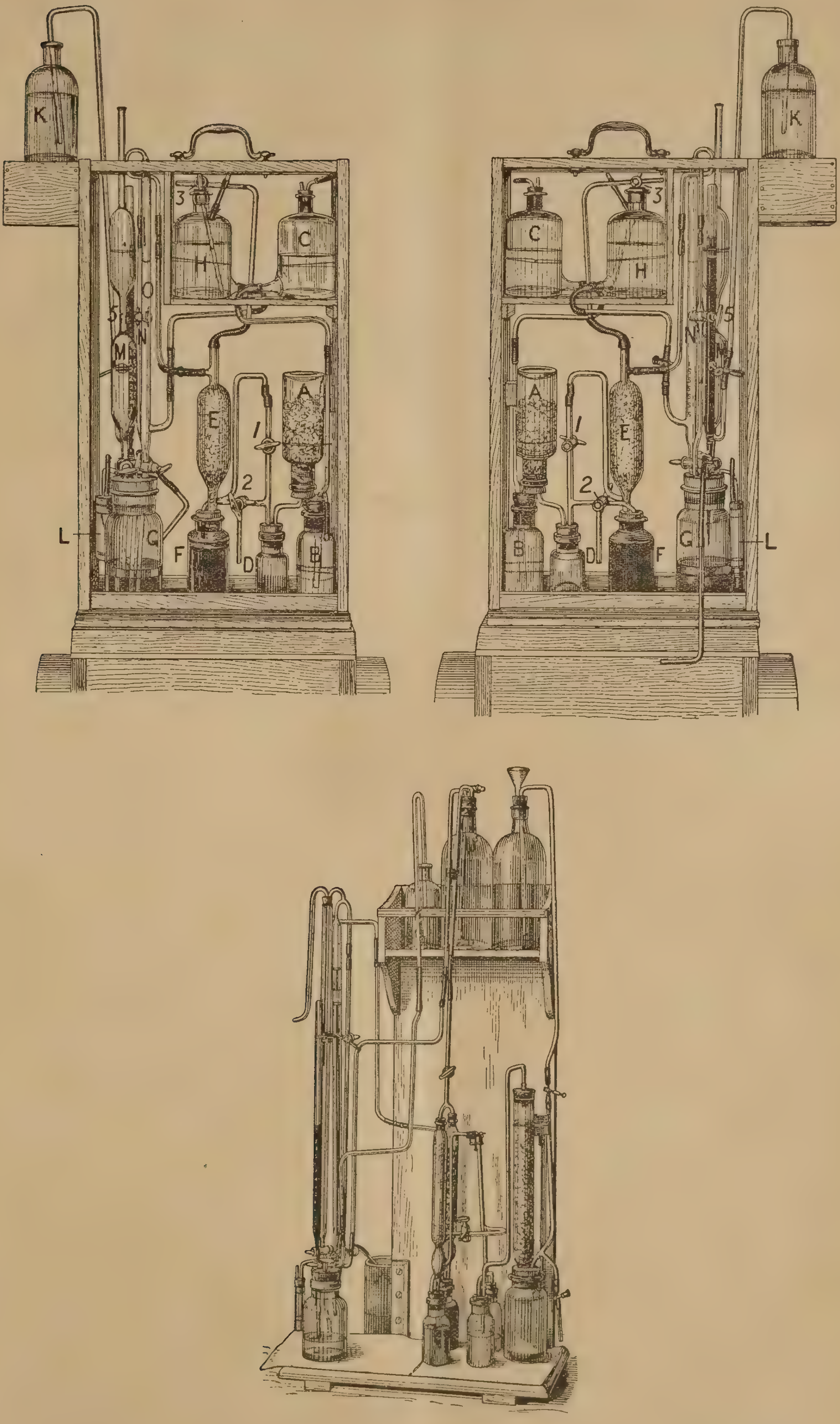
Dissolved oxygen apparatus.—The arrangement of the apparatus as used by me for the determination of the "dissolved oxygen" in water is similar in principle to that described by Roscoe and Lunt, in the Chemical Society Journal, Vol. 55, August, 1899, page 552, also *see* Sutton's Volumetric Analysis, 8th edition, page 297, *et seq.*, but modified so as to make it portable.

The main parts of the apparatus are 1st, a hydrogen apparatus which can give a constant stream of pure hydrogen under pressure, and 2nd, the estimation bottle having an indiarubber stopper with six holes holding three burettes (for sample, indigo, and hypo respectively), an inlet and outlet tube for hydrogen, and a tube for emptying the bottle. The apparatus was designed to be the same size as an ordinary Orsat gas analysis apparatus. The photographs shew the apparatus as in use, and its construction is as follows :—

Hydrogen apparatus.—Bottles A B C form a simple arrangement for the generation of hydrogen under pressure, acting in the same manner as a "Kipp." From the top of bottle (A), a tube passes to bottle (D), in which there is a little caustic soda. The stopcock (1) regulates the supply of hydrogen which passes to bulb (E), filled with beads, and saturated with alkaline pyrogallic to free the gas from any trace of oxygen. The hydrogen then divides, one part going to the hyposulphite stock bottle (H), while the remainder passes to the top of the hypo burette, which has a T tube fused on, and allows the burette to have an atmosphere of hydrogen above the hypo, while the remainder of the gas passes through stopcock (5) into the bottle (G), from which it escapes through the water seal tube (L) to the atmosphere.

To saturate the beads with alkaline pyrogallic.—Each day before the apparatus is used, the beads in (E) have to be saturated with pyro from the bottle underneath, which is done thus : stopcock (1) is closed and the three-way stopcock (3) opened to the air. The three-way stopcock (2) is opened gradually, and the hydrogen forces the pyrogallic from (F) up to (E) ; stopcock (2) is then turned to allow the pressure in bottle (F) to escape, when the liquid falls back to (F). This is once repeated to saturate thoroughly. Stopcock (2) is then shut off from the hydrogen, and No. 1 opened, when the hydrogen drives any air from (E) through (3) to the atmosphere ; No. 3 is then turned to allow hydrogen to get into bottle (H).

PHOTOGRAPHS OF THE DISSOLVED OXYGEN APPARATUS REFERRED TO IN ENCLOSURE II. TO MR. FRANK SCUDDER'S REPLY.



Mr. F. Scudder.

To fill the hyposulphite burette.—Each day the hyposulphite lying in the burette must be driven back into bottle (H), and the whole mixed. This is done by opening (3) to the air, and, turning the two-way cock fitted on the burette, the hydrogen pressure blows back the hyposulphite to bottle (H), and bubbles for a few seconds to mix. Cock (3) is turned to allow the hydrogen into the bottle, and the hyposulphite at once runs back to the burette.

The indigo burette is an ordinary 25 cc. burette open to the atmosphere, and is filled by means of a wash bottle.

Hydrogen is now blown through the apparatus for ten minutes to get rid of any trace of oxygen, and the sample of water to be estimated in bottle (K) connected by siphon with the water burette having a two-way stopcock.

When ready to start, 20 cc. of water are run from bottle (K) into the water burette to wash the connections from air, and to seal the water burette tube under liquid in bottle (G), 5 cc. of indigo are also run in. This is now decolourised exactly with hyposulphite to a clear yellow colour, and the water and hypo burettes brought to zero. Water is now run in slowly underneath the sensitive yellow liquid, which at once turns blue; a few drops of hypo are added as required to keep the blue colour down to a faint blue till the whole of the 100 cc. of water has been added, when the hypo is added cautiously till the clear yellow colour is obtained as at start. The burette is then read off. If the determination has to be repeated, then the finger is held on the exit of tube (L), stopcock (5) opened, when the pressure of the gas drives the water out of the estimation bottle through a tube which touches the bottom of the estimation bottle, into an outside vessel at the back of the apparatus, about 20 cc. being left in for next estimation. 5 cc. indigo are now added, and the process repeated. When the sample is finished, with a tube fixed in a stopper in the top of the water burette enables the water to be blown back to bottle (K), which is then replaced by the next sample.

FRANK SCUDDER, F.I.C.

44, Mosley Street, Manchester.

(*Second Letter.*)

Mr. FRANK SCUDDER, F.C.S., F.I.C.

44, Mosley Street,
Manchester,
July 2nd, 1903.

Dear Sir,

Re Standards for Sewage Effluents.

B. *Effluents which may pass into a Drinking-water Stream.*

Question 5. In answer to this question, I am of opinion that no water from a stream which has received sewage effluent ought to be used for drinking purposes. In my professional capacity as a chemist, I am constantly reporting on the quality of water used for drinking purposes, especially in the case of "well" waters, and if I find any indication that such water is contaminated with sewage organic matter, I reject such water as unfit for drinking purposes. The fixing of standards for sewage effluents which may pass into a drinking-water stream is a delusion and a snare. Of course, I am aware, for instance, that London derives its water supply from a river into which sewage effluents are discharged, but the question resolves itself into a consideration of the ratio of sewage effluent to river water. The effect of dilution is such, that when such water is submitted to an efficient system of filtration it is supplied to the people of London, and we know that the only efficient filtration, from a sanitary point of view, is that which removes the whole or almost the whole of the living microbes from the water. The fixing of standards such as I have referred to in the case of effluents which pass into a non-drinking-water stream have no application in this case, having regard to the fact that in drinking-water the presence of organisms and their character is of paramount importance in forming a judgment as to the quality of the water for drinking purposes.

In reply to Question 6, I do not think it practicable to sterilize sewage effluents.

In answer to the last question, viz., "Whether it is easier to treat on a given area of land or filter a small volume of a strong sewage or a larger volume of a weak sewage, the total amount of organic matter in each volume being equal?" on the whole, I should prefer to deal with the smaller volume of sewage, as the area can be better manipulated, and more time given for oxidation, but so much depends on the quality of the organic matter (manufacturing sewage varying so much in different centres), that the question cannot be answered without a great deal of proof and reference to many cases.

I am, yours truly,
Frank Scudder.

F. J. Willis, Esq.,
Secretary, Royal Commission on Sewage Disposal.

Mr. F. WALLIS STODDART, F.I.C., F.C.S.—PUBLIC ANALYST FOR CITY AND COUNTY OF BRISTOL SALISBURY AND BRIDGWATER. LECTURER IN UNIVERSITY COLLEGE, BRISTOL.

Western Counties Laboratory,
Bristol
June 8th, 1903.

STANDARDS FOR SEWAGE EFFLUENTS—REPLY TO CIRCULAR LETTER.

(*A*) *Effluents which will pass into a Non-Drinking-Water Stream.*

1. Yes. I think some form of standard is necessary as a means both of coming to a decision as to the most satisfactory methods of purification and of enforcing the application of such methods.

2. In selecting the standard I think the following considerations should be borne in mind :—

(*a*) A single standard and not standards should, if possible, be selected. This standard may, of course, be composite as suggested, for instance, in paragraph 2 (*a*), that is to say, an effluent may be called upon to comply with two or more tests simultaneously, but there should not be alternative standards. Unless, however, the individual tests cover really separate requirements they are best omitted, that is to say merely corroborative tests should not be included in an official standard.

(*b*) The standard should be based on a test or tests requiring the least possible time and work, because in order to decide whether a given form of treatment is satisfactory it is absolutely necessary to make frequent independent tests under all conditions, and it is not sufficient to make an average test of material collected over an extended period. As this may involve fifty or more separate tests within twenty-four hours, it is imperative that no complicated or laborious operations be called for. A contingent advantage is that with the simpler test there is less danger of conflicting results, and consequent expensive litigation.

(*c*) The test selected should be one unaffected by reasonable delay in the examination of the sample, and

(*d*) Should directly indicate the suitability or otherwise of the effluent to be discharged into a stream.

On applying these considerations to the various standards classified in paragraph 2 of the circular letter it appears :—

a) That a standard of non-putrescibility upon incubation complies with all requirements It is simple, requires but a few moments of personal attention, and that of the least technical character, and is therefore almost incapable of giving contradictory results in the hands of different observers ; it is not affected by delay in the examination of properly-collected samples, but is indeed proceeding from the moment of collection ; finally, it gives a direct reply to the question at issue, inasmuch as it merely reproduces the conditions to which the evils of sewage pollution are due.

The only practical objection to this test, namely, the length of time required for incubation, is largely met by the modification suggested in a note published in the "Analyst," xxvi., 281, a copy of which I enclose. This note also contains a proposal for detection putrefactive changes which materially simplifies the usual procedure.

With effluents derived from domestic sewage, or from sewage which, though containing trade waste, retains the character as a whole of domestic sewage, I am convinced no other test is required. Any reference in such cases to either organic matter, or the rate of oxygen absorption, I should regard as introducing merely corroborative tests previously referred to as best omitted. The rather theoretical objection that an effluent, though putrescible, may possibly be sterile, is readily met by a direction to suitably inoculate the sample ; but in practice this is effected by not cleaning the sample bottles between tests.

In order, however, to meet all cases, I think it will be necessary to combine with the test for non-putrescibility certain others directed towards the detection of undesirable matters introduced with trade wastes of a kind likely either to inhibit bacterial action, or to injuriously affect the animal and vegetable life of streams. These tests will have particular reference to the presence of free acid, and of germicidal or poisonous matters in the effluent.

(*b*) I am opposed to the association with the above test of another based on the rate of oxygen absorption, for the reason that speculative considerations are at once introduced, and in some cases conflicting results are certain to be obtained.

(*c*) Absolute standards such as that of the Mersey and Irwell Joint Committee are, in my opinion, wanting in all essentials ; in fact, I would go further and say that nothing has so largely assisted in retarding the satisfactory solution of the sewage problem as the forced application of methods of analysis originally devised for the totally different purpose of determining the potability of water. The tests referred to are much too complicated, give most discordant results in the hands of experienced observers, and, most important of all, entirely fail to distinguish between a dilute but putrescible sewage and a strong but perfectly innocuous effluent.

Mr. F. Wallis Stoddart.

(d) The ratio of oxidised to unoxidised nitrogen is a test of totally different character, and could, I believe, be made a reliable indication of the condition of an effluent were the necessary data at our disposal. Even so, however, the uncertainty connected with the establishment of the required ratio, and the comparative complexity of the operations involved, render such a test markedly inferior to one which directly and in the simplest manner gives the desired information.

3. I do not consider it advisable to complicate the incubator test with the, in my opinion, less satisfactory test of absorption of oxygen from surrounding water, partly on the general grounds noted above, but also for the special reason that the main point to be kept in view in this connection is not the affinity for oxygen of the effluent as produced, but as it will be during and after the prevalence of putrefactive changes, should these be possible.

3a. Assuming that any such test is adopted I am inclined to think that a standard of 50 per cent. of the saturation quantity persisting after twenty-four hours is a reasonable one, my reason for saying so being that I have generally found that an effluent which on other grounds I have considered good has complied with this limit, though I cannot say that I have carried out any extensive research in this direction.

(B). *Effluents which may pass into a Drinking-water Stream.*

5. Whilst I am in favour of a standard for sewage effluents generally, I do not think that any useful modification can at present be suggested for effluents discharged into a source of drinking-water.

I am satisfied that it would not be feasible to propose a standard that would ensure an effluent being perfectly safe as a beverage. The official recognition of any standard short of this would at once be used as an argument for, and would in some quarters be considered a justification of the admission of such sewage effluent as complied with it into water of this kind. I believe that in this way the danger which undoubtedly attaches to water supplies into which sewage or sewage effluent is admitted would be very much increased. It is, I think, generally recognised that it is at present impossible to ensure the absence of pathogenic organisms from effluents under all conditions; it would very much weaken the effect of any legislative measures to include unattainable standards, and in my opinion the best course is to continue the present practice of selecting water supplies as far as possible out of reach of sewage, whether treated or not, relying in less satisfactory cases on the most efficient treatment of the water immediately before its distribution to the consumer.

6. I think it may be possible, at least in some cases, though at considerable cost, to sterilise the dry weather effluent; but I am satisfied that it is quite impossible to deal in this way with the wet weather flow at a time when the conditions are most dangerous.

In reply to the last paragraph, it is undoubtedly easier to treat on a properly constructed filter, in which there is no danger of waterlogging, a larger quantity of dilute sewage than a smaller quantity of strong sewage, the organic matter being the same in both. This only applies in a limited degree to land and to such filters as become readily fully charged with liquid to the exclusion of air. But as long as the air supply remains good it is undoubtedly the case, and I think a reasonable explanation is found in the consideration that the quantity of dissolved oxygen capable of being brought into contact with each unit of oxidisable matter is directly in proportion to the amount of water in which that matter is dissolved or diffused. I have now had filters of the class referred to under observation for upwards of four years, and I have invariably found the most difficult time to secure a consistently good effluent to be during continued drought, when the sewage, though small in bulk, remains exceptionally concentrated for some length of time.

F. Wallis Stoddart.

Enclosure to Mr. F. Wallis Stoddart's Reply.

"THE ANALYST," NOVEMBER, 1901.

THE INCUBATOR TEST FOR SEWAGE EFFLUENTS.

By F. Wallis Stoddart, F.I.C.

The incubator test stands alone amongst the various means devised for determining the quality of a sewage effluent, in that it affords a direct and conclusive proof of conformity, or the reverse, with the requirements of the Rivers Pollution and Public Health Acts. Offences against these Acts, with the exception of the improper deposition of solids, are the result of putrefactive changes. The ordinary analysis of an effluent and its relation to dissolved oxygen afford valuable but only indirect evidence of its liability to putrefaction, the deductions drawn from the analytical data being further based upon premises not universally accepted, whilst the analysis itself is far too cumbrous a performance to apply sufficiently often to give a reliable insight into the character of so variable a liquid as sewage effluents commonly are; the incubator test, on the other hand, goes at once to the root of the matter, can be applied to any reasonable number of samples, and gives results which require no further elaboration.

The method of carrying out this test is thus described in the "Experts' Report on Treatment of Manchester Sewage": "A determination is first made of the oxygen absorbed from potassium

Mr. F. Wallis Stoddart.

permanganate by the sample in three minutes. A bottle is then completely filled with the sample, and placed in the incubator at 80° F. for six or seven days. The three minutes' oxygen absorption is then again determined. If any putrefaction has taken place, the oxygen absorbed in three minutes will exhibit a decided increase in amount owing to the more ready oxidizability of the products of putrefaction, such as sulphuretted hydrogen, etc. On the other hand, if the sample keeps sweet, the three minutes' oxygen absorption remains practically unchanged after incubation, or there will be a slight decrease owing to slight oxidation of the impurities which has taken place during the period of incubation at the expense of the nitrate or dissolved air present in the sample."*

The test under these conditions is not entirely satisfactory, and does not distinguish with sufficient sharpness between good and bad effluents, as may be seen on reference to the Manchester report, in which the increase in oxygen absorption by unfiltered tank effluent rarely reaches 50 per cent., and even the crude sewage occasionally shows complete stability.

With the view of improving this test, and reducing, if possible, the length of incubation, I have carried out a number of experiments with sewage products of various kinds, and, chiefly by raising the temperature of incubation, have succeeded in so far emphasizing the distinction between putrescible and imputrescible liquids as to have arrived at a test which might well be adopted in connection with any future legislative measures. The liquid to be tested should be enclosed in well-stoppered bottles, which should be quite full. Mercury valves are objectionable, as the mercury is attacked and fixes an appreciable amount of the sulphides formed in putrefaction. The incubating temperature should be 37° C., when much more active changes will ensue than at 27° C., resulting in a much more copious production of reducing bodies. The bottle should be well shaken before the measured quantity is taken for the estimation of absorbed oxygen.

With unfiltered tank effluent a marked increase in absorption is noted after three days, but the change is much more pronounced at the end of a week, and continues for a considerably longer period.

It is found that the formation of sulphide runs parallel with, and is no doubt the chief cause of, the increase in oxygen absorption; this being so, the test may be still further simplified by substituting the addition of lead solution for the permanganate process, and, if necessary, a colorimetric estimation may be made, for which purpose a solution of lead chloride will be found to be preferable to the usual acetate. For all practical purposes, however, a visible darkening on addition of the lead test after incubation for from three to six days is all that is required, and this is the form of criterion I should suggest for official purposes; any effluent that will give evidence of putrescibility under the current test will be readily detected in this way. Indeed, the modified test is, if anything, too severe, and will be found to condemn many effluents which comply with the usual standards; as, however, it is now possible by modern methods to continuously convert sewage into a liquid capable of passing the modified test at a single expenditure of a few shillings per head of population, no great injustice would be inflicted by its adoption.

The following table illustrates the application of this test to unfiltered precipitation and septic effluents:

INCUBATOR TEST.

Three Minutes' Oxygen Absorption of Unfiltered Precipitation and Septic Effluents before and after Incubation at 37° C. in full Bottles.

Length of Incubation in Days.	Fresh.	1.	2.	3.	4.	5.	7.	8.	9.	10.	11.	12.
Precipitation effluent -	0·700	0·700	0·727	0·952	1·30	1·40	1·456	1·624	1·638	1·68	1·736	1·960
Percentage increase -	—	—	12	36	86	100	108	132	134	140	.48	180
Septic effluent - - -	0·560	0·560	0·694	1·12	1·68	1·89	1·994	2·036	2·13	2·156	2·268	2·436
Percentage increase -	—	—	24	100	200	236	256	264	280	285	305	335

The formation of sulphide as indicated by the lead test is exactly parallel with the oxygen absorption.

It would be anticipated on theoretical grounds that the septic product would be a more putrescible and offensive liquid than the precipitation effluent, and that if treatment were limited to tank operations, as is even now sometimes suggested, chemical purification would be more effective than septic action alone. It is interesting to note the more copious and rapid production of oxidizable (and offensive) bodies in the much weaker septic effluent in the above table, a change which however, presents marked advantages where the tank product is applied to the aerating filter now universally recommended.

Mr JOHN C. THRESH, M.D., D.Sc., F.I.C., Medical Officer of Health to the Essex County Council.

Reply to Questions by Royal Commission on Sewage Disposal.

Chelmsford.
May 23rd, 1903

1. I do not favour fixed standards of purity, but in Essex I have been compelled to give a temporary standard for the effluents flowing into the Roding and the Rom. *Vide* printed form enclosed. At the present time it is rare that an Essex effluent comes up to this standard. When the standard is reached then I shall try gradually to raise it, as I think better effluents should be obtainable. The only effluent which passes the standard is that from the Romford Sewage Farm.

2. The printed form enclosed practically answers this question. I may add that my experience is that even the best sewage farm effluents encourage vegetable growths in streams when the effluent forms a fair proportion of the whole flow.

3. The test devised by me is naturally the one I prefer. It gives me such results and with such ease that I have never cared to test any more recently-devised process. I recommend adding 100 cc. of effluent to 400 cc. of water (tap), shaking vigorously for about five minutes in a Winchester. Then take half, and measure the dissolved oxygen therein. Allow other half to stand in the oxygen tube for 24 hours, and again estimate the dissolved oxygen.

Some years ago I tried a number of effluents in this way, and came to the conclusion that the test was not of much, if of any, value, as effluents which I regard as unsatisfactory chemically gave fairly good results tested in this way. The following are results recently obtained with effluents from Buckhurst Hill Sewage Works. :—

Raw sewage	Oxygen absorbed in 24 hours	per litre	67·5	mlgr.
Septic tank effluent	,, ,,	,,	43·2	,,
Primary bed effluent	,, ,,	,,	21·0	,,
Secondary bed effluent	,, ,,	,,	4·0	,,

The secondary bed effluent gives on analysis—

Free ammonia	2·40	grains per gallon.
Organic ammonia	·11	,, ,,
Oxygen absorbed	1·14	,, ,,
Nitric and nitrous nitrogen	·88	,, ,,

Nearly the whole of the free ammonia is capable of oxidation to nitric acid, as, by passing it through about 12 inches of polarite and sand which I keep in an "active" condition, I can in a few minutes effect this change.

3. I have long ceased to make any careful determinations of the dissolved oxygen. A simple test of my own suffices, in my opinion, for practical purposes. I add to a sample collected in a small, wide-mouthed, stoppered bottle a soloid of pyrogallic acid and one of caustic soda (these and bottle I carry in my pocket). By the depth of tint produced I can judge with sufficient accuracy as to the degree of oxygenation.

4. My chief reason for opposing any definite standard is my ignorance as to what we may ultimately find is reasonably practicable in the way of purification. I hope that we may be able to affect far greater degrees of purification than is at present accomplished. Moreover, in Essex I cannot require so high a degree of purification for effluents flowing into tidal rivers already very foul as into the non-tidal portions or into inland streams. Moreover, when the Lea and Thames Conservancy pass such effluents as they apparently now regard as satisfactory, it is difficult for me to insist upon anything much better.

5. I should certainly want a much higher standard of purity when the effluent is allowed to flow into a river from which drinking water is obtained. In this case there should, if possible, be a bacteriological standard. I do not think, in the present state of my knowledge, that I should be justified even in suggesting a standard.

6. It certainly is possible to sterilise sewage, but the only way in which I have seen it done is at Liernur's works at Trouville, where the effluent is distilled water.

With reference to the action of land on weak or strong sewage I have made no experiments, but from my observations of sewage farms I should say that with proper management it would be much easier to treat on a given area of land a small volume of strong sewage than a large volume of weak sewage.

John C. Thresh,
M.O.H., Essex County Council.

Enclosure to Dr. Thresh's Reply

ESSEX COUNTY COUNCIL.

ANALYSES OF SEWAGE EFFLUENTS AND RIVER WATERS.

Notes to assist in the Interpretation of Results, so far as they refer to Sewage Effluents.

Colour.—A good effluent should have no appreciable colour when viewed in a column three inches in depth.

Odour.—A good effluent should have no offensive odour even after being kept for several days in a warm place (98° F.)

Turbidity.—This is expressed in degrees varying from 0 to 100. 0 represents perfect freedom from suspended matter. A liquid with a turbidity of 100 contains so much suspended matter that a column half an inch in thickness entirely obscures black lines on white paper. A satisfactory sewage effluent should not have a turbidity exceeding 10°.

Degree of Oxygenation.—Raw sewage contains no free oxygen. An effluent fully saturated has a degree of oxygenation expressed by 10. The more nearly an effluent is saturated the better its quality.

Chlorine.—Usually the amount of chlorine present (in combination as sodium chloride) gives some indication of the strength of the sewage, but in districts where the chlorides in the public water supplies vary in quantity, or where chlorides are added to the sewage, the amount present has little significance.

Nitrogen as Nitrates and Nitrites.—Bacterial purification of sewage results in the formation of nitrites and nitrates. The more efficient the purification the greater the amount of these substances in the effluent.

Free and Albuminoid Ammonia.—The lower the figures for the ammonias, the better the effluent. A fairly good effluent should not yield more than ·10 grain of albuminoid ammonia per gallon.

Oxygen Absorbed.—The smaller the amount of oxygen required to oxidize the organic and other matters the better the effluent. After keeping, the oxygen absorbed should not increase. After three hours the oxygen absorbed should not exceed 1·0 grain per gallon.

Mr. A. H. VALENTINE, M.Sc., Chemist to the OLDHAM CORPORATION.

(*First Letter.*)

Laboratory : Foxdenton Lane, Hollinwood,
Oldham,
July 24th, 1903.

DEAR SIR,

You must excuse my apparent remissness in not replying to your circular letter of May last. I did intend, however, writing you, explaining my position as to the evidence I could bring forward on the points raised in the circular; but I allowed the matter to fall into abeyance for reasons which follow.

I have been only a short time, comparatively speaking, at Oldham, and though I am gradually accumulating data on which to base definite opinions, yet I am afraid the work up to date is not exhaustive enough to enable me to formulate such. I hope that it may be possible, within two or three months, to let you have a full and concise answer to the circular.

In the meantime, I beg to tender my general opinion on the points raised. That, I am afraid, will not be of any great value, and will be practically no help to the Commission.

I am in favour of some fixed standard of purity, fixed, that is, in reference to the particular sewage in question. As to the principles upon which this standard should be based, I have not yet made up my mind.

At present I am doing experiments which I trust will enable me to answer questions 3 and 3a

At Oldham, as you know, we are not concerned in attempting to produce an effluent which would be fit to turn into a stream from which drinking water is obtained. Yet it seems obvious that a much higher standard is required for such effluents. The amount of albuminoid nitrogen should be almost at vanishing point, and what nitrogen there is should be either in the form of nitrates or of elementary nitrogen. This would show, at any rate, efficient filtration. The greatest factor, in my opinion, is that of dilution; so that where the sewage of a large population has to be treated, it would seem impossible to consider the advisability of running the filtered effluent into any running stream of drinkable water unless the stream, reckoned by its daily flow past a certain point, be of much greater volume (by multiple) than the daily flow of filtered effluent; and, in any case, a final filtraton or straining through sand or other fine material would seem necessary. This, however, is a matter more concerning the bacteriologist than the chemist.

I have no grounds for thinking that it would be possible to sterilise sewage. It seems impossible to consider the idea with regard to the sewage of a large population. I do not know that it is possible to obtain *absolute* sterilisation in a large volume of water, and, if it were possible, how long the water would remain sterile to all forms of bacteria. Of course, I bear in mind also the great expense involved in producing sterility by chemical means.

I hope to be able to say something later upon the rider immediately above your name.

In conclusion, I hope you will excuse me when I say how utterly impossible it seems to dogmatise upon the many difficult points raised in the circular. I hope, however, to be able to narrow down my opinions by the time I write next.

Yours faithfully,
A. H. VALENTINE.

F. J. Willis, Esq.,
Secretary, Royal Commission on Sewage Disposal

(*Second Letter.*)

THE OLDHAM CORPORATION.

Sewage Works : Foxdenton Lane, Hollinwood, Oldham.
October 10th, 1903.

Re Circular Letter on "Standards."

F. J. Willis, Esq., Secretary,
Royal Commission on Sewage Disposal.

SIR,

I beg to forward my answers upon the questions put me in the Circular, May, 1903.

As regards the question dealing with fixed standards of purity, I am afraid that I must modify the opinion previously expressed by me when I wrote last July. I have performed a very good number of analyses, determining the "4 hrs. O. absorption," "the absorption of dissolved O. from aerated water," the oxidised N., ammoniacal N., and "albuminoid" N. After careful revision of the numbers and quantities thus obtained, I confess that I see no relationship beween any two sets of determinations that would lead me to state any fixed standard of purity dependable upon *figures.* On the other hand, the only reliable test for effluents running into a non-drinking water stream seems to be that of incubation. And as a matter of fact, the whole question of river and stream pollution appears to depend upon the superficial observation of the general public upon the special characteristics of the appearance and odour of the waters of a stream. No doubt there can be, however, that a systematic determination of the various "elements" in waters exercises a fairly secure check upon filtered effluents in the hands of the chemist, etc., placed in charge of a sewage works.

Mr. A. H. Valentine.

With reference to a standard based upon the amount of O. absorbed from $KMnO_4$ during four hours, I have had effluent from filters which have taken up less than one grain per gallon of O., and yet have become putrescent in the incubator; and on the other hand, there have been filtrates which have taken up more than two grains per gallon, but have remained "sweet" in the incubator. Similar observations with reference to the amount of "albuminoid" N. have been made.

It seems possible, however, to apply a fixed standard based upon the four hours test where a purely domestic and fairly constant sewage is concerned, such as one might get from large villages and small towns. And certainly, the provisional standard of the Mersey and Irwell Joint Committee does not seem too harsh for such cases. But to apply the same rigid standard to a sewage which receives a fair quantity of adventitious (as regards time) trade effluent seems manifestly unfair. It would be sufficient that the filtered effluent from such a sewage should pass satisfactorily the incubator test.

If I remember rightly, you have already received my opinions upon the other points raised in the circular.

As for the enquiry "whether it is easier to treat on a given area of land or filter a small volume of strong sewage or a larger volume of a weak sewage, the total amount of organic matter in each volume being equal," my limited observations lead me to the conclusion that it is easier within limits to treat the larger volume of the weak sewage. Not only does the percentage purification become greater, but there is a very great tendency for the filtered effluents to remain non-putrescent in the incubator, where the effluent from the strong sewage would probably become putrescent.

I remain,

Yours sincerely,

A. H. VALENTINE, M.Sc.

Dr. H. Maclean Wilson.

Dr. H. MACLEAN WILSON, M.D., B.Sc., CHIEF INSPECTOR TO THE WEST RIDING OF YORKSHIRE RIVERS BOARD.

REPLIES TO QUESTIONS ON STANDARDS FOR SEWAGE EFFLUENTS.

(A). *Effluents which will pass into a Non-drinking-water Stream.*

1. No.

2 (a). This is a basis much too narrow. There is, moreover, no evidence, so far as I know, to show the effect of an effluent which may be non-putrescible on incubation upon a stream into which it is discharged in a large quantity.

(b). This basis is a little wider and more definite than the last, but is not sufficiently so.

(c). I do not consider the standard is sufficiently high as a fixed standard, nor that it takes into consideration a sufficient number of factors. Many effluents from sewage farms are so good that they do not absorb more than 0·5 parts per 100,000 of oxygen in four hours at 80° F., and they do not contain more than 0·05 of albuminoid nitrogen, and it is quite possible for sewage to be so purified regularly and continuously so that these figures in the effluents are not more than doubled. The amount of nitrates present should be taken into consideration as evidence of the extent to which purification has progressed, and as forming a factor in the further purification, and the amount of dissolved oxygen in the effluent should also be considered as showing to some extent what effect the effluent will have upon a stream. With a knowledge of these four figures: the oxygen absorbed, the albuminoid nitrogen, the nitrates, and the dissolved oxygen, a well-founded opinion can be given as to the probable result of an effluent upon a stream.

(d). While these ratios have some value as a guide to the purity of an effluent, they are by no means sufficient.

With regard to the suggestion that the residual organic matter in an effluent derived from strong sewage is less fermentable, a standard based on the four figures mentioned above would not be effected by this.

While the effect of an effluent upon the bed of a stream is of the most serious importance, it is not possible to base any standard upon it in the present state of our knowledge. I would suggest, however, that the presence of a growth of the ordinary grey offensive sewage fungus upon the bed of a stream should be taken as definite evidence that the effluent is not satisfactory.

3 and 3a. Sufficient data have not yet been obtained to warrant a standard being based upon these.

4. A definite standard is, I believe, impracticable and inadvisable; impracticable, because, for example, it is impossible for a district with a peculiarly strong sewage or with peculiar difficulties in the way of sewage treatment to produce an effluent such as is easily attained by a district with an ordinary domestic sewage and with ample means for its purification. Moreover, it would be absurd to ask that a sewage effluent to be discharged into a navigable stream of large volume should be quite as pure as one to be discharged into a pure upland stream of small flow, and thus at once considerations of the circumstances of a place and of the nature of the stream into which the effluent is to be discharged must arise; inadvisable, because a fixed legal standard, unless fixed so high as to be discouraging to, and at present practically unattainable by, many large communities would only hamper the progress of sewage purification.

(B.) *Effluents which may pass into a Drinking-water Stream.*

5. As according to present knowledge it seems quite impracticable to purify sewage so as to free it from pathogenic germs, the water of a stream into which sewage effluents have passed should not be used for drinking purposes.

With reference to the statement that the Commission are advised that the state of the stream cannot lawfully be taken into account in considering whether an effluent infringes the provisions of the Rivers Pollution Prevention Acts, the following judgment in the High Court of Justice, King's Bench Division, before the Lord Chief Justice of England (Lord Alverstone), Mr. Justice Darling, and Mr. Justice Channell, Hainsworth *v.* The West Riding of Yorkshire Rivers Board, 25th February, 1902, may be of interest.

MR. JUSTICE DARLING:—" I am of the same opinion. It was first of all argued by Mr. Macmorran that the matter which went in from this factory was not polluting liquid. He admitted. and it is stated in the evidence which he read, that if it were put into a pure stream it must be considered a polluting liquid, but it is said it is not a polluting liquid here because the stream already contained so much similar matter, or worse matter. It seems to me that in order to find out whether that is the intention of Section 9 we must look at what the Act was intended to do, and if I turn to the recital in the preamble I find this: 'Whereas the filthy and polluted condition of the said rivers, or parts thereof, and their tributaries urgently requires improvement.' So that what they were aiming at obviously was to get this stream back to its pristine and original condition, if possible, or, as My Lord says, towards it.

" Then we ought to look at it, it seems to me, somewhat as if you want to find out what is a polluting thing, looking at it as a natural stream flowing with natural water. If you look at it in that way this was a polluting matter, and I think that, although it was not so bad as some of the other polluting matters—and as to some of them it may have been remedied against them—the object of the Statute is to get rid of them all—every one—and you cannot say you shall begin at the top of the stream, but you must not begin at the bottom. I think you may begin anywhere, and treat any of them as polluting matters if it interferes with what was the original character of the stream."

The comparison between the ease of treatment of a small volume of strong sewage or a larger volume of weak sewage of a given area of land or filter is not a subject to which I have paid any particular attention.

H. MACLEAN WILSON,
W.R. Yorks Rivers Board.
Chief Inspector.

22nd June, 1903.

ADDENDA.

Enclosure I. to Dr. Adeney's Reply.

THE COURSE AND NATURE OF FERMENTATIVE CHANGES IN NATURAL AND POLLUTED WATERS, AND IN ARTIFICIAL SOLUTIONS, AS INDICATED BY THE COMPOSITION OF THE DISSOLVED GASES. (PARTS I., II., AND III.) BY DR. W. E. ADENEY, ASSOC. R.C.SC.I., F.I.C., CURATOR AND EX-EXAMINER IN CHEMISTRY IN THE ROYAL UNIVERSITY, IRELAND.

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INTRODUCTION.

It is, I believe, now generally accepted that the organic matters which, by one means or another find their way into surface waters, are oxidised, and eventually reduced to simple substances by the operations of micro-organisms, and not by mere chemical changes independent of them. To these operations the term "fermentation" is usually applied.

This explanation rests chiefly on the results of bacteriological research, and especially upon the fact that the germs of these micro-organisms are present, practically, everywhere—in the air, in water, and in ordinary soil; and that they require but the necessary pabulum, such as refuse animal or vegetable matters, in a neutral or slightly alkaline medium, for rapid growth and multiplication.

The importance, from the chemist's point of view, of the recognition of the true agencies at work in setting up processes of oxidation in natural and polluted waters, does not appear to have been sufficiently realized.

It suggests at once the possibility of classifying the organic matters to be met with in natural and polluted waters into two classes, viz., fermentable and non-fermentable, and of differentiating the one from the other when present in the same water.*

We know that some of the organic matters found in natural waters either do not ferment at all, or do so with difficulty, such as peaty colouring matters and the organic matters found in good well and spring waters. Of a like character, also, are those which are found in sewage-water after they have undergone complete fermentation under aerobic conditions, such as obtain during slow filtration through sand or soil.

Amongst the fermentable matters may probably be included most, if not all, known organic substances, with the exception of antiseptics. Dr. Munro has shown, in his interesting and suggestive paper on "The Formation and Destruction of Nitrates and Nitrites in Artificial Solutions and in River and Well Waters," † that not only are such simple bodies as acetates and oxalates attacked by the organisms usually present in soil and water, but also such unlikely substances as ethylamine, cyanides, thiocyanates, and he concludes that it would be difficult to make out a list of known organic compounds which are not fermentable under these conditions.

One of the most obvious results of the fermentation of small quantities of an organic substance in fully aerated water would, no doubt, be an absorption of the dissolved atmospheric oxygen therein, and an evolution of carbon dioxide; and if the water were preserved during fermentation under conditions such that gases could neither escape from, nor gain access to it, these results would also be the most easily detected by chemical means.

A few tentative experiments carried out on the lines here suggested showed very distinctly that the above view was correct, and that even relatively minute quantities of fermentable matters such as fresh sewage, when mixed with good river water, soon indicated their presence by causing an absorption of dissolved oxygen, and an evolution of carbon dioxide.

These experiments satisfied me that the consumption of oxygen and the formation of carbon dioxide, which must occur during the fermentation of small quantities of organic matters in a water, when taken together, provided a most delicate indication of the presence of such matters in a water.

But little consideration, however, was necessary to lead one to anticipate that a method of inquiry, based upon the determination of the changes in composition of the dissolved gases, would lead to much more definite results, especially when coupled with the determination of the inorganic nitrogenous products of the fermentation—such fermentation to be conducted under suitable conditions.

In explanation of my meaning, I would refer to the more recent researches on nitrification.

Dr. Munro,‡ Dr. P. F. Frankland,§ and Mr. Warington,|| have all demonstrated that the fermentation of ammonia to nitrous acid may occur in inorganic solutions to which no organic matters have been added. M. Winogradsky** has extended these observations, and has not only shown that a nitrous fermentation proceeds when organic matters are rigorously excluded from the cultivating inorganic solutions, but he has also demonstrated that organic matters are formed from inorganic materials at the same time, the first step in their formation possibly being, as suggested by him, the production of an amide from ammonium carbonate.

We find, moreover, abundant evidence given in Munro's Paper, that unfermented non-nitrogenous organic matter is positively prejudicial to nitrification, and that, if present with ammonium

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* It is due to Dr. Dupré to make reference in connection with this point to a short Paper by him entitled—"On Changes in Aeration of Water, as indicating the Nature of the Impurities present in it," and published in the Report of the Medical Officer to the Local Government Board, 1884.

† "Chem. Soc. Journ.,' vol. 49, p. 677 See also p. 651.

‡ *Loc. cit.*, p. 653.

§ "Phil. Trans.," 181, p. 107.

|| "Chem. Soc. Journ.," 59, p. 484.

** "Annales de l'Institute Pasteur," vol. iv., pp. 213, 257, 769; vol. v., pp. 92, 577.

salts in a water containing soil or water organisms, they undergo fermentative changes before nitrification sets in.

We have evidence also from the same author's Paper that the nitrification by soil organisms of *nitrogenous* substances, with no added ammonium compounds, follows a similar course. A putrid bacterial fermentation first takes place, during which nearly the whole of the organic nitrogen is converted into ammonia, and this ammonia apparently only begins to undergo nitrification after the first fermentation of the organic matter originally present has been completed.

If, then, the nitrification, by the mixed organisms which ordinarily occur in soils and natural waters, of organic substances containing nitrogen, or mixtures of these containing no nitrogen with ammonium compounds, takes place in two distinct stages as above indicated, it is probable that accurate determinations of the more obvious products of each stage of fermentation, viz., carbonic dioxide and possibly ammonia in the one; and of carbonic dioxide (if any be formed) and nitrous and nitric acids in the other, together with accurate determinations of the free oxygen consumed during both stages, would afford *data* for estimating the actual quantity of fermentable matters present in polluted water with sufficient accuracy for the purpose of water analysis.

Such a method of examination as here suggested promised results of a most definite character and of especial value for the examination of polluted drainage waters, in that they would probably afford the means of accurately estimating the quantity of such water which could be safely allowed to drain into a river or stream of a given size, and would thereby lead to the possibility of formulating exact practical standards of impurity for drainage waters, which standards could be graduated according to local conditions of volume and flow of the streams.

The method of examination which I have sketched was, however, open to possible objections, which could only be answered one way or the other by a full experimental investigation. For instance, a water under examination would always contain mixed organisms, and the selective chemical functions of these might vary to such an extent that in no two experiments with the same water would similar values for the products formed, or oxygen consumed, be obtained. It might further be objected that a given result was due to the accidental presence of a particular organism.

There were, however, good reasons for believing that, if precautions were taken to experiment under certain conditions, as regards the relative quantities of fermentable matters, and of dissolved oxygen, the growth of similar sets of organisms, so far as chemical functions are concerned, would be encouraged, and that the products obtained thereby would be very similar in chemical characters.

The actual quantity of carbon dioxide, and no doubt of nitric acid, but probably to a more limited extent, formed relatively to the quantity of oxygen consumed during fermentation of similar volumes of different polluted waters, would no doubt vary with the composition of the organic matters originally present in them. But, for the purpose of water analysis, this would not affect the value of the quantity of oxygen consumed, as a quantitative index of the amount of the fermentable matters originally present, since this quantity would probably exactly represent that which a similar volume of the same water would require when discharged into a natural watercourse.

It must be remembered, too, that, by the complete fermentation under aerobic conditions of organic matters in an ordinary water, much the greater proportion of the organic carbon and organic and ammoniacal nitrogen undergo complete oxidation to carbon dioxide and nitric acid respectively, and only a very small proportion of either of these constituents remains fixed as fermented organic matters, and that variation in fermentative products due to selective chemical action of the mixed organisms present would probably be shewn most prominently in the last mentioned products, viz., the fermented organic matters.

With these considerations in mind, I commenced a series of experiments as long back as the autumn of 1891. The slowness, however, of some of the fermentative processes under observation, combined with long-continued interruptions in the course of the work by other duties, has hitherto prevented my being in a position to publish any results. The scope of the investigation has also widened, and very many points have arisen and demanded experimental study, which were not anticipated at the commencement of the work. Even now, I cannot claim to have finished the investigation of many of these points.

My experiments, however, in so far as the original object of the investigation is concerned, have now reached a sufficiently advanced stage, I think, to render any further delay in publication undesirable. I therefore propose, in this communication, to deal with such experiments as bear directly on the question with which I started this investigation, viz., *whether the amount of the dissolved oxygen consumed during the complete fermentation of a polluted water might not be regarded, for the purpose of water analysis, as a quantitative index to the amount of fermentable substances originally present in it, provided that during the process care is taken to have the oxygen in excess in the water.* And, further, whether it might not be possible to separately estimate the volume of dissolved oxygen consumed during each of the two distinct stages in which it is supposed the nitrification of organic matter takes place. I say supposed advisedly, because it cannot be regarded as having been experimentally proved that the nitrification of nitrogenous organic substances, or of non-nitrogenous organic substances mixed with ammonium compounds, really takes place in two stages except when the fermentation is carried on under partially aërobic and partially anaërobic conditions. There can be little doubt, for example, that in Munro's* experiment on the nitrification of gelatine, in which, during the earlier stages of fermentation, he noticed putrefactive products and the formation of ammonia, free oxygen must have been entirely absent from the lower layers of the solution he employed, judging from its strength.

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* *Loc. cit.*, p. 641.

Dr. Adeney.

It cannot be taken for granted, therefore, that the oxidation by fermentation of gelatine, or other nitrogenous substance, in the continued presence of an excess of free oxygen, would be "progressive," as above described, rather than "complete from the commencement."*

I may, however, anticipate in this particular, the experiments which I have to describe, and state that they all go to show that the fermentation of such bodies by the mixed organisms of soils and waters takes place in two perfectly distinct stages, even in the continued presence of free oxygen, and that in the first stage the organic substance is simply broken down, the carbon and nitrogen, if present, being converted largely into carbon dioxide and ammonia, a small quantity of organic matter, however, remaining as such, but in an altered form; that in the second stage the ammonia is oxidized to nitrous or nitric acids, or both, and that, at the same time, the organic matters resulting from the first stage may be partially or completely oxidized, carbon dioxide and possibly nitric acid being formed; also that the second stage does not commence until the completion of the first. I shall call these two "first" and "second" stages of fermentation for want of better terms; new terms are, in fact, wanted to describe them properly. My friend, Dr. E. A. Letts, has suggested to me a term which seems to be very suitable for the first, viz., bacteriolysis.

METHOD OF EXPERIMENTING.

In considering this question, three conditions which the method adopted would be required to fulfil, had to be borne in mind:—

1. It should not be possible for any gas during an experiment to gain access to, or egress from, the vessel in which the experiment was to be carried on.

2. It should be possible to easily and accurately regulate the quantities of dissolved oxygen and of fermentable matters relatively to one another in a liquid to be examined, so that the former should be in excess of the latter, or *vice versa*, just as required.

3. The external conditions of a liquid during fermentation should be similar in all respects, and such as to ensure as far as practically possible that every part of the liquid throughout its mass should be chemically similar at any interval of time during the continuation of the experiment.†

These necessary conditions made it impossible for me to use the method of liquid cultivations, as commonly employed by bacteriologists, viz., nutrient liquid media, in which the relative quantities of fermentable matters and dissolved oxygen are not specially regulated, and which are kept in bottles or in flasks, which they only partially fill.

With such a method it would be quite possible, as bacteriologists have generally observed, to have a fermentation in the continued presence of an excess of atmospheric oxygen proceeding in the portions of the liquid immediately adjoining the surface exposed to the air in the vessel in which it was kept, and at the same time a fermentation in the practically complete absence of dissolved oxygen in the lower portions of the liquid. The only possible way of ensuring the third condition above stated, was to keep the water or liquid under observation in bottles completely filled and carefully closed with glass stoppers. The difficulties to be anticipated in practically carrying this out were those which would certainly arise with unavoidable alterations of the temperature of the liquid during the continuance of the experiment. With fall of temperature, there would be a tendency to draw air into the bottle, and with a rise there would be a tendency to expel a portion of the liquid from it, while with both rise and fall of temperature, there might be a disengagement, and possibly, in consequence, a loss of dissolved gases.

I found, however, that by keeping the bottles immersed, neck downwards, in distilled water, in large glass vessels which were covered with glass plates, and by exposing them to a temperature as equable as possible, that these difficulties could be overcome to such an extent that they could not give rise to errors sufficiently large to materially affect the results.

I shall again refer to this subject when dealing generally with the probable errors of the experimental results.

The foregoing consideration of the third necessary condition to be established in my method of experimenting has, it will be observed, included the first. There remains now for discussion the second condition.

For the purpose of this Paper it was of chief importance to observe the products of fermentation which had been carried on in the continued presence of an excess of oxygen relatively to the quantity of matter to be fermented.

It was also of importance to determine whether the complete fermentation, on the one hand, of the nitrogenous organic matters, and, on the other hand, of non-nitrogenous organic matters mixed with ammonium compounds, into carbon dioxide, water, and nitrous or nitric acids, in the continued presence of an excess of oxygen, was complete from the commencement or was progressive.

To effect these purposes, I adopted the general plan of commencing with strong solutions of sewage-waters, or of fresh peat, or of organic and inorganic substances of known strength and composition, in which the quantities of fermentable matters were in decided excess, relatively, to the quantity of dissolved atmospheric oxygen present, and then of making a series of gradually increasing dilutions with good tap-water, or, when necessary, with distilled water, such that the conditions should gradually become reversed, the dissolved oxygen in the higher dilutions

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* See Schützenberger on "Fermentation," p. 244. International Scientific Series, 1891.

† In connection with this point, see Dr. P. F. Frankland and Mr. Frew's very interesting experiments described in their Paper on "A Pure Fermentation of Mannitol and Dulcitol."—C. S. J., 61 p. 254.

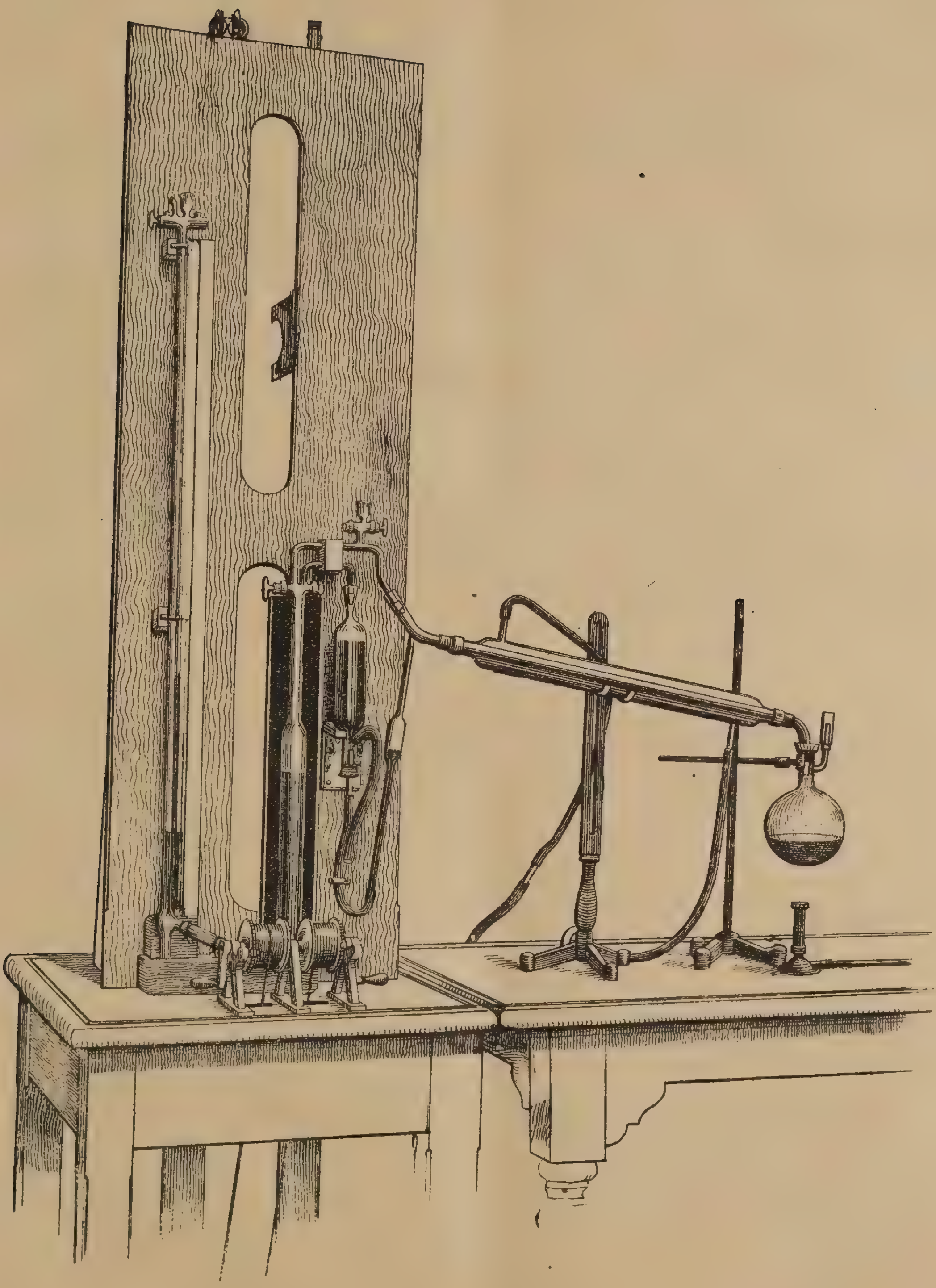

FIG. 7. ADENEY'S APPARATUS FOR THE EXTRACTION AND ANALYSIS OF GASES DISSOLVED IN WATER.

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Dr. Adeney.

becoming predominant in quantity. By this means I hoped to obtain results which would quantitatively indicate the changes resulting from the fermentation of various fermentable matters under gradually varying condition from that in which the fermentable matters were in excess to that in which the dissolved oxygen was in excess.

One further general condition which had to be attended to in all the experiments need scarcely be mentioned; it was to make provision for keeping the liquids under observation in a slightly alkaline condition during fermentation. This was invariably done by adding, when necessary, very small quantities of pure dry sodium carbonate, which consisted partly of the normal carbonate and partly of the bicarbonate. When experimenting with sewage-water, it was found to be quite unnecessary to add any of this or other mineral substances. All the solutions were kept in the dark during fermentation.

APPARATUS EMPLOYED.

The bottles I have employed for preserving the waters or solutions under experiment, out of contact with air, have been made in two forms: one, the ordinary bottle-form with short necks; the other of flask form, with long, somewhat narrow necks. Both forms have been made of stout glass with very carefully ground stoppers. The capacity of the bottles has varied, according to circumstances, from about 300 c.cs. to 2,500 c.cs.

As before stated, the bottles, when filled, were carefully stoppered so as to leave not a trace of air bubble in them. To avoid the possibility of small quantities of air passing into them between the neck and the stopper, they have been kept neck downwards immersed in distilled water. Under these circumstances, a little distilled water might be drawn into the bottles, or a little solution expelled from them, but not in sufficient quantity to introduce material error, provided the temperature of their contents was not allowed to vary much. When, from any cause, such as considerable variation of temperature, or the formation of gaseous products, other than carbon dioxide, during fermentation, disengagement of gas during the course of an experiment was to be anticipated, such gas would remain in the bottle, since this latter was kept neck downwards, and some liquid would be expelled from it between the neck and the stopper. It would be necessary, of course, to collect this gas, and separately measure and analyse it. To meet this special case, the flask-shaped bottles, with long narrow necks mentioned above, were employed. The neck of each bottle was graduated from the bottom of the stopper downwards, as follows: the bottle was completely filled with water, and the stopper firmly inserted; the stopper was then carefully taken out, and the height of the water was marked on the neck with a diamond as zero, the graduation was then proceeded with by withdrawing the water half a cubic centimetre at a time, and marking on the neck the height of the water as each half c.c. was withdrawn. The neck being graduated in this way, it was possible to note immediately before displacing the disengaged gas, which was done over distilled water, the volume of water which would enter the flask and become mixed with its contents; the capacity of the flask, with the stopper inserted, and the composition of the gases dissolved in the distilled water being known, it was in this way possible to calculate and correct for the error which the admission of the distilled water into the flask would introduce in the estimation of the dissolved gases in the liquid under experiment.

The form of apparatus which I have used for extracting the dissolved gases, measuring and analysing them, is shown in the accompanying drawing. It consists of a mercury-pump combined with a gas analysis apparatus, and can be used for all three operations required in the examination of the gases dissolved in liquids, viz., for their extraction, measurement, and complete analysis. The remaining parts of the apparatus which are shown in the sketch consists of a Liebig's condenser of glass, and a round-bottomed stout glass flask with a side tube from the neck.*

The flask, which for convenience of reference I propose to name the laboratory flask, is made of sufficiently stout glass to bear a vacuum. The only points of importance, so far as shape is concerned, are that it must be round-bottomed, and that the neck must be somewhat long and tapering to allow of the short india-rubber cork, by which the inner tube of the condenser is packed air-tight into it, fitting sufficiently deep down to leave a space above itself for a water or mercury luting.

The capacity of the flask should be about four times the volume of liquid to be boiled in it. It is convenient to have two sizes, viz., 1,500 c.cs., and 2,500 c.cs.

The laboratory flask is employed for conducting the necessary operation of boiling the liquid under examination in vacuo, for the extraction of the gases dissolved in it. Since the condenser to which it is attached cools down, and condenses the aqueous vapour given off during the process of boiling, the liquid may be heated to violent ebullition continuously for any required length of time without fear of unduly raising the pressure of the vapour and gases in the flask.

The gas analysis apparatus proper, shown in the drawing, is an improved form of that which I have already described in a Paper, published in the "Scientific Proceedings of the Royal Dublin Society."† To that Paper I would refer for a more complete description of the principles of the apparatus and its applicability to other operations than that here described.

In this Paper I will only give a short description of the apparatus shown in the drawing sufficient to explain the improvements which have been made on the older form, and to render intelligible the use of the apparatus for the purposes of this research.

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* The glass parts of the apparatus were obtained from Messrs. Baird and Tatlock, of Glasgow and London.

† "On an Apparatus Applicable for Gas Analysis and Other Purposes."—Scien. Proc. R.D.S., vol. vi., pt. IX., p 555 (1890). Reprinted in the "Chem. News," 62 pp. 196--199, and 204--206.

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Its essential parts are a gas burette and laboratory vessel, differing in many respects in form and use from those generally employed in other forms of gas-analysis apparatus, and a long pressure-tube provided at its upper end with a Friedrich's patent glass stopcock.

The form of the burette is exactly similar to that employed in my older apparatus. It is contracted at its lower end, and passed through a hole cut in the centre of the indiarubber bung which closes the lower end of the glass cylinder, enveloping the burette, and which thus provides a means of keeping the burette surrounded with a water-jacket. It is then bent at right angles, and joined to the pressure tube by indiarubber tubing lined with canvas, and tightly wired to the glass tubes. The bottom of the cylinder, the joint and bent portions of the burette and pressure-tube sit in a trough cut out, and suitably shaped from a piece of solid mahogany, and which, during work, is kept filled with mercury to protect the indiarubber joint from the air.

The way in which the glass cylinder, burette and pressure-tube are supported is indicated in the drawing, but this will be more clearly understood from the drawing of the older form of the apparatus.

The supply of mercury to the burette and pressure-tube is regulated by means of a reservoir, which rests in a wooden box, suspended by a catgut line, and capable of moving freely from the top of the apparatus to the floor. It is prevented from swinging by a grooved guide fixed to the back of the apparatus, in the grooves of which slide corresponding portions of the box. The catgut line passes over the necessary lead pulleys to the windlass mentioned below.

The reservoir box can be raised or lowered by a small winch or windlass fixed in front of the apparatus, as shown in the drawing, and fixed at any point by the rachet cut on one side of the winch drum. The flexible tube from the reservoir passes through a hole, cut in the wooden upright supporting the apparatus, at a point just below the level of the side branch from the pressure-tube, and is attached thereto.

It is essential that the flexible tube from the reservoir should be attached to the pressure-tube, and not directly to the burette, because, when the reservoir is kept for any length of time at a lower level than that of the bottom of the burette—and this is constantly necessary when employing the apparatus as a vacuum pump, or when measuring gases under very low pressure—there is a tendency for air to diffuse through the indiarubber tube. With this arrangement, if an appreciable quantity of air does thus diffuse during an experiment, it passes up into the pressure tube when the reservoir is raised, and can be driven out when necessary through the stopcock at its upper extremity, without in any way affecting the experiment; as a precaution against the air being carried round into the burette by the inflowing mercury, the pressure-tube is expanded considerably where the side tube is attached to it, as shown in the drawing.

The upper end of the burette is provided with a Friedrich's patent two-way stop cock, by means of which communication with the laboratory flask, or a laboratory vessel, to which it is connected by the branch tubes shown in the drawing, can be opened or closed at will.

The upper branch tube leading to the condenser and flask is 3 mm. bore; the lower branch is a capillary tube.

The two branch tubes are held against a wooden block, shown in the drawing, in cork-lined grooves, by a brass plate, also cork lined, and screwed to the block. The grooves are made sufficient in width to allow of considerable play in a vertical direction.

This last precaution is necessary to allow for alteration in length of the burette induced by changes of temperature. When the tubes are properly fitted in these grooves, there is no danger whatever of their being broken, even if the apparatus is subjected to careless handling.

The contracted portion of the upper part of the burette is about 225 mm. long, and has a capacity of 15 c.cs., the wider portion being about 410 mm. long, with a capacity of somewhat more than 250 c.cs. Both portions are graduated, the former at intervals of one-tenth c c., and the latter at intervals of 25 c.cs.

The pressure-tube has a working length of 1,000 mm. above the level of the lowest division, viz., the 250 c.cs. line of the burette.

The height of the mercury in the pressure tube is read by means of a millimetre scale etched on the unsilvered surface of a narrow slip of looking glass, which is fixed to the back of the apparatus, close to the pressure tube, at such an angle as to reflect the image of the tube through the portion of the glass bearing the scale. To read the height of the mercury in the tube the eye is held a little to the right of the scale, and moved about until the scale-lines in the immediate vicinity of the reflected image of the mercury meniscus coincide with their own images reflected from the silvered surface of the glass. When the eye is in this position, the height of the mercury in the tube can be accurately read to 0·5 mm.

The laboratory vessel differs in principle and shape from that used in Frankland's and M'Cleod's apparatus. Its shape is shown in the drawing; the lower end, which is cylindrical in shape, is 25 mm. diameter, and 55 mm. long, and is furnished with a side tube for connecting the vessel with a separate reservoir. The middle portion of the vessel is 160 mm. long, and the upper end as an inverted conical shape, which is 55 mm. long, the diameter increasing from 3 or 4 mm. at the lower, or narrow part, to 20 mm. at the mouth.

Two platinum wires are sealed into the vessel in the position shown in the drawing.

The special shape given to the upper portion of the laboratory vessel enables it to be easily connected, or disconnected with the burette. When the vessel is placed in position, as represented in the drawing, the capillary branch tube, the end of which is fitted with an indiarubber collar, tightly closes the narrower part of this portion of the vessel, while the lower shoulder of the vessel rests upon a shelf (shown in the drawing) which has somewhat the shape of a horseshoe. If the space above the rubber collar at the end of the branch capillary tube be filled with mercury or water, a perfectly air-tight joint is obtained. The joint may, in fact, be made so staunch, that a vacuum can be maintained in the vessel, or, on the other hand, explosions may be made therein without fear of loss.

When it is desired to disconnect the laboratory vessel, its lower portion is drawn forward sufficiently to clear the shelf, and it is then lowered to detach it from the branch tube from the burette.

By reversing these movements, the laboratory vessel may be again placed in its position. The shape of the indiarubber collar is of importance; its lower end must be shaped so as to bear well on the sides of the contracted portion of the laboratory vessel. The collar is easily given the necessary shape by means of a red-hot iron wire. The lower end of the laboratory vessel is closed by a well-fitting cork, through the centre of which passes a straight glass tube about 10 mm. long and 3 mm. bore; to the outer end of this a piece of stout indiarubber tubing, about 15 cms. long and 1 mm. bore, is attached.

When the cork is fixed into its place, the other end of this glass tube projects into the laboratory vessel for about 2 ctms. A small Bunsen screw-clamp is provided, with which to open or close the rubber tube when necessary.

The glass tube supplies the means of introducing gaseous or liquid reagents into the laboratory vessel, and I therefore propose to call it the reagent tube.

The side tube from the lower portion of the vessel is as I have already stated, connected by means of a rubber tubing, with a separate reservoir, which is supported in a box,* and raised or lowered along guides fitted at the back of the apparatus, by means similar to those already described as provided for the reservoir to the burette.

The shelf which supports the laboratory vessel is, in reality, a small bracket, the vertical limb of which is provided with a tongue at the back, sliding in a groove cut in the wooden back of the apparatus, so that, thus guided, it can be moved up and down in a vertical direction, and clamped at any point by a thumb-screw, so as to adjust the amount of pressure, which the upper end of the laboratory vessel will exercise on the rubber collar.

This adjustment provides for all alteration, either in the length of the laboratory vessel, owing to changes of temperature, or in the size of the rubber cork, owing to wear or replacement, and ensures an air-tight joint with the capillary tube from the burette at all times.

The whole apparatus is supported on a strongly-made table, 91 ctms. high.

The method of working the apparatus is as follows:—The pressure tube, burette and laboratory vessel being filled with mercury, and all stopcocks closed, the laboratory vessel is placed in its position in the manner just described. The laboratory flask, into which 50 c.cs. of pure distilled water have been placed, with or without the addition of 1 or 2 c.cs. of pure sulphuric acid, as the experiment may require, has been placed, is fitted to the end of the condenser. The water in the flask is then boiled, the air and steam escaping through the side tube in the neck of the flask. The end of this tube is fitted with a short piece of indiarubber tubing. After continuing the boiling for about ten or fifteen minutes, the burner is removed from under the flask, and at the same time the short rubber tube, attached to the side tube from the neck, is closed with a piece of glass rod.

By this operation the flask is largely freed from air; the air still remaining in it, and in the condensing tube is next drawn off by working the apparatus as an air-pump. This is done by lowering the burette reservoir to its lowest limit, the mercury flowing out of the burette, leaving it in vacuo. If now the stopcock of the burette be turned to open communication between it and the laboratory flask, aqueous vapour and portions of the residuum of air left in the flask will pass into the burette. The stopcock is then turned to close communication with the laboratory flask, and the reservoir raised to refill the burette with mercury. The air and water drawn into the burette by this operation are then passed into the laboratory vessel by opening communication therewith. By this time the neck of the flask and the side tube therefrom will be sufficiently cooled to allow of water being safely poured into the space left in the neck above the rubber cork, by which the condensing tube is fitted into the flask, to protect it from the air, and to fill a water-jacket over the piece of rubber tubing closing the side tube.

The operation of drawing aqueous vapour and gases from the laboratory flask into the burette, and driving them thence into the laboratory vessel is repeated until the mercury, or rather the condensed water on the top of the mercury, strikes the closed stopcock of the burette with a sharp metallic click when the burette becomes full of mercury. In this way the burette provides an extremely sensitive means of gauging the degree of exhaustion which can be obtained in the laboratory flask. The flask is usually exhausted by the time the burette has been filled with mercury, and emptied four or five times. The flask being exhausted, preparations are immediately made to transfer a known volume of the water to be examined, into the laboratory flask.

A few minutes' delay is first allowed to allow the surplus water left on the sides of the burette to collect at the top.

This is then transferred to the laboratory vessel, which is next detached from the capillary branch tube, care, however, being taken before doing so, to leave the branch tube full of mercury.

The rubber collar is detached from the end of this tube, which is then connected by means of a piece of indiarubber tube with a glass tube of the same thickness and bore as itself (27 ctms.

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* The position of this box is not quite correctly shown in the drawing. Its true position will, however, be understood from the description in the letterpress.

Dr. Adeney, long), which has been previously completely filled with the water to be examined. The lower end of the latter tube is immersed in the water for examination, the burette reservoir lowered a little, and the stopcock opened, the water then passes into the burette.

By gradually lowering the reservoir, 250 c.cs., or a less volume if required, of the water may be drawn into the burette.

When this has been effected, the stopcock is closed, and opened to the laboratory flask. The water then passes into it from the burette, care being necessary to prevent mercury getting into the flask during the operation. The glass tube is now detached from the capillary branch, the rubber collar reattached, and the laboratory vessel refixed in position. It is now necessary to clear the laboratory vessel of small bubbles of air, and of any decided quantities of water that may remain on its sides or in the reagent tube from the process of washing after the previous analysis. This is rapidly done by raising the reservoir decidedly above the level of the side tube of the vessel, and unscrewing the clip which closes the rubber tube attached to the outer end of the reagent tube, so as to allow mercury to pass into the pipette attached to the other end of the rubber tube and supported by a clip, fixed to the stand, in the position shown in the drawing. The reservoir is then dropped considerably, and the screw-clip being cautiously opened, the greater portion of the mercury in the pipette is drawn back into the laboratory vessel, carrying with it any air-bubble or water which may have lodged in the reagent tube. The clip being closed, the reservoir is raised sufficiently to cause the mercury to overflow the laboratory vessel when it is slightly withdrawn from the rubber collar on the capillary branch tube, thus driving out the air and water from the top of the vessel. The laboratory vessel is refixed in position, and the reservoir is then lowered so as to empty the vessel almost completely, and being rapidly raised, note is made as to whether the sharp click is heard when the vessel refills completely. If not, it is again partly detached from the collar, and some mercury driven out, and the vessel again replaced in position. These operations of causing the mercury to overflow the top, lowering the reservoir so as to nearly empty, and again rapidly refilling the vessel, are continued till the sharp click, indicative of complete exhaustion, is obtained. Generally this is obtained after two or three trials, the operation being extremely easy.

During the time occupied in these manipulations, the water in the laboratory flask is kept violently boiling to disengage the dissolved gases.

These are drawn into the burette from the flask, and stored in the laboratory vessel in a similar manner to that described for exhausting the flask in the first instance, with the exception that the condensed aqueous vapour, drawn into the burette with the dissolved gases, is not allowed to pass into the laboratory vessel, but is returned to the flask. When the dissolved gases have been completely extracted, a few minutes delay are allowed for the small quantities of water, adherent to the sides of the burette, to rise to the top, when it is returned to the flask. The measurement and analysis of the gases stored in the laboratory vessel is then proceeded with.

The method of adjusting the level of the mercury in the burette, after the gases have been passed into it, will require some explanation. The simple plan of closing the stopcock, and then raising and lowering the reservoir so as to bring the mercury to the level of the division line selected cannot always be followed, since, after transferring the gas, a small bubble of it sometimes remains in the laboratory vessel under the rubber collar, and cannot be removed therefrom. When, therefore, the level of the mercury in the burette is being adjusted, the stopcock must be left open, and the adjustment be made by working the two reservoirs conjointly. To transfer the gases into the burette in the first instance, its reservoir is lowered, and that of the laboratory vessel is raised, if necessary, until nearly all the gas is passed over, a little, however, remaining in the laboratory vessel. It must be observed at this point whether the gas will require to be compressed or expanded in order that the mercury in the burette shall stand, after final adjustment, at the level of the division line selected for measurement, and in order that, at the same time, the laboratory vessel shall be completely filled with mercury, with the exception, possibly, of the small bubble of gas above referred to; with careful manipulation, however, no bubble of gas need remain. With a little practice, the adjustment may be effected easily and quickly. An indication that all the gas possible has been transferred to the burette at the final adjustment is obtained when the mercury, or more generally water, since a small quantity always collects in the laboratory vessel during the operation of extracting the gases from the laboratory flask, and storing them, as above described, rises a little in the capillary branch tube.

When the necessary adjustments have been made, the height of the mercury in the pressure tube, which, I should here note, is kept moist, is read off, the line of measurement on the burette and the temperature of the water in the jacket are also noted. The next step is to absorb the carbon dioxide; the small quantity of solution of potassium hydrate required for this purpose is introduced into the laboratory vessel thus:—the stopcock of the burette is closed, the reservoir of the laboratory vessel is fixed well above the level of the reagent tube, and a pipette containing the solution of potassium hydrate is connected to the free end of the rubber tube attached to the reagent tube, and then left supported, as indicated in the drawing.

As the reservoir is now above the level of the reagent tube, on unscrewing the clamp the mercury will flow into the pipette, and expel any small bubble of air that may have been left in the open end of the rubber tube after attaching the pipette to it. The air having been completely expelled, the clamp is screwed up again, and the reservoir dropped to a level a little below that of the reagent tube.

On carefully opening the clamp the mercury in the pipette will slowly flow back into the laboratory vessel, and after it the required amount of potash solution, care being used so as not to empty the pipette entirely. As soon as this is accomplished, the clamp is closed, and the reservoir raised to about its former level. The surplus quantity of solution remaining in the reagent tube may now be driven back into the pipette, and after it a little mercury, by carefully opening the clamp, which is closed again immediately this has been done. To effect the absorption of the carbon dioxide by the potash, the gas is passed into the laboratory vessel and then backwards and forwards into the burette three or four times, care being taken not to allow any of the potash into the burette. In about five minutes the carbon dioxide will be completely absorbed, and the remaining gas again measured just as before, and the height of the mercury in the pressure tube noted, the difference of reading before and after absorption giving the pressure exerted by the carbon dioxide at the volume at which the gases have been measured.

If the volume of this gas has been large, it will reduce the errors of reading in the further process of analysis, if the remaining measurements be made at a volume less than that which was necessary before absorbing the carbon dioxide. The operation of absorbing the oxygen by means of pyrogallic acid is carried on similarly to that for absorbing the carbon dioxide. The remaining gas will consist, at least in most cases, of pure nitrogen. Its pressure at the volume at which the measurements for the determination of the oxygen were made, is easily determined by deducting from the last-noted pressure the height of mercury in the pressure tube corresponding to the height of mercury in the burette at the line at which the measurement for the determination of the oxygen was made. This height may be quickly determined for each experiment by noting the height of mercury in the pressure tube, when the mercury in the burette is adjusted at the said line of measurement in vacuo.

The residual gas, after the absorption of the carbon dioxide and oxygen, may in some cases contain hydrogen, and possibly marsh gas.

When this is the case the following procedure is adopted:—

After carbon dioxide and oxygen have been absorbed and determined, the remaining gases are driven back into the laboratory flask, and the laboratory vessel and burette are very carefully cleaned.

To do this the reagents in the laboratory vessel are driven gradually above the rubber collar on the end of the capillary branch tube by lowering the vessel a little from the collar, and carefully raising its reservoir. As the reagents rise above the collar they are absorbed by means of blotting paper. When the vessel has been cleansed by this means as far as possible, it is replaced in position, and about 50 c.cs. of dilute sulphuric acid (1 : 3) are introduced into it through the reagent tube. A little of the acid is allowed to rise above the rubber collar to neutralize the potash adherent to it, and the remainder is drawn into the burette.

The laboratory vessel is then completely detached from the capillary branch tube, and the acid, after having been drawn down nearly to the bottom of the burette, is discharged from it into a beaker.

The laboratory vessel is next placed in position and filled with tap-water through the reagent tube, and a similar series of operations again carried out as above described, with the view of washing both vessel and burette free from acid; the washing is repeated two or three times with distilled water.

When the operation of washing has been completed, the liquid in the laboratory flask is boiled, and the gases drawn from it into the burette and laboratory vessel, with the precaution previously described for their complete expulsion. After their measurement, some pure oxygen is introduced into the laboratory vessel through the reagent tube in a manner exactly similar in principle to that above described for the introduction of liquid reagents. The mixed gases and oxygen are then measured, and exploded under reduced pressure, and the further analysis proceeded with in the ordinary way.

Since the water surrounding the burette becomes unequally heated during the process of extracting the gases from the laboratory flask, it is necessary to replace it before measuring and analysing the gases. This is readily done by syphoning off the water immediately after the process of exhausting the flask has been completed, and replacing it with some that has been exposed for some time to the temperature of the laboratory.

I ought to note, before concluding this description, that it has been ascertained by experiments, which are detailed in my Paper on the earlier form of the apparatus already referred to, that the bubble of gas, which is sometimes retained in the laboratory vessel during measurement, does not introduce appreciable errors therein.

Extraction of the Gases in Solution.

Although it is impossible to completely exhaust a water of the gases it holds in solution in vacuo in the manner I have described, it is nevertheless possible to carry the exhaustion so far that the quantities of the respective gases left behind in the water may be disregarded, as experience has shown that they do not appreciably affect the results.

Both oxygen and nitrogen are readily extracted from the water, and transferred to the laboratory vessel for measurement by three or four exhaustions of the flask during the boiling of the water in it, but the carbon dioxide is not so easily disengaged, and between a quarter and half an hour's ebullition in vacuo is usually necessary to effect its removal, the length of time depending on the quantity of this gas in solution, and also, apparently, upon the dissolved mineral matters also, a hard water requiring more boiling than a soft one.

Owing to the slowness with which bicarbonates decompose when boiled, I have found it practically impossible to determine, separately, the "combined" and "uncombined" carbon dioxide in a water. But the total carbon dioxide is readily estimated by boiling the water with a suitable acid, and by the term carbon dioxide I shall hereafter always include the combined carbon dioxide with that which may be held in solution uncombined.

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The acid I have used for this purpose has invariably been sulphuric acid. When its presence has been necessary, I have always added it to the water placed in the flask in the first instance, preparatory to exhausting the air from the flask, as already described.

The presence of the acid does not interfere with the determination of the oxygen and nitrogen, unless, of course, nitrites are present in the water. When this is the case, the dissolved oxygen and nitrogen are determined in the absence of acid, and the carbon dioxide afterwards estimated by a separate experiment in the presence of acid.

I have generally employed 250 c.cs. to 500 c.cs. of a water for the analysis of the dissolved gases; such volume of water giving suitable volume of gases for the apparatus. The operation of extracting and analysing the dissolved gases in a water may generally be completed within two hours.

METHODS EMPLOYED FOR THE DETERMINATION OF INORGANIC NITROGEN.

The nitrogen as ammonia has been determined in the ordinary way by nesslerizing after distillation, with the exception of a few cases, when it was necessary to directly nesslerize without previous distillation, owing to the fact that the substances experimented with were decomposed on boiling.

The method employed for estimating the nitric acid was that which has been worked out by Williams,* and which depends upon the action of a "zinc-copper couple" in reducing nitrates and nitrites to ammonia. My general experience with this method is, that it gives reliable results.

For the estimation of nitrous acid, I have employed Griess' metaphenylenediamine method, as detailed in Sutton's "Volumetric Analysis," p. 367, 5th edition.

Wherever possible, that is when the total quantity of inorganic nitrogen has not been large, I have preferred to subject the water to the action of the "zinc-copper couple" before distilling off the free ammonia present.

The nitrogen as free ammonia then obtained, after the action of the couple, represents the total inorganic nitrogen. This amount, less that as free ammonia originally present, and nitrous acid, which are separately determined, gives the nitrogen present as nitric acid.

When, however, the free ammonia or nitrous acid is present in large quantity, I have separated them in the ordinary way, the free ammonia by distillation, and the nitrous acid by distillation in the presence of an excess of ammonium chloride, before examining the water for nitric acid. I have occasionally employed Crum's method with Lunge's nitrometer to check the results obtained with the zinc-copper couple method, and have usually obtained concordant results therewith.

ERRORS.

The methods of experiment which I have described, are liable to three distinct sources of error. They are:—

1. The possible changes in volume which the dissolved gases may suffer during the manipulation necessary for bottling the water, and transferring it to the gas analysis apparatus.

2. The operations in the gas analysis apparatus, viz., the extraction and analysis of the dissolved gases.

3. The changes of temperature which the solutions undergo during the time of keeping them in bottles, as described, out of contact with air.

It would be difficult to give a precise value for each of these three sources of error, but their total effect upon the final results obtained, which are, it must be remembered, the differences between the determinations for each dissolved gas before and after keeping the liquid under the prescribed conditions, will be found approximately indicated in the majority of the experiments which I shall describe in this Paper, by the atmospheric nitrogen determinations.

Since most of my experiments have been carried on under more or less aërobic conditions, the atmospheric nitrogen has not, except apparently in a few cases, suffered changes in common with the other bodies with which it has been associated. The difference between the volume of this gas before and after fermentation, therefore, affords a very valuable index of the extent to which the above possible sources of error affect the analytical results.

The total error may also be found practically by blank experiments with the water employed for making up the solutions.

I have usually found the difference between the determination of the volumes of nitrogen before and after keeping to be under 0·2 c.c. per litre of water. In some cases it has risen nearly to 0·3 c.c., but this is exceptional.

Blank experiments with tap-water, the particulars of which will be given later on with the details of my other experiments, show that the oxygen determinations before and after keeping do not usually differ by more than 0·1 c.c., and rarely differ by as much as 0·15 c.c. per litre of water.

The error attending the determination of carbon dioxide varies somewhat with the quantity and probably also with the composition of the mineral matter in solution in the water. When the quantity is not greater than 40 or 50 c.cs. per litre, the error is about the same as that affecting the nitrogen determination, but, as the quantity increases, the error is liable to slowly increase also, and may reach to as much as 1·0 c.c. per litre for quantities amounting to 200 c.cs. per litre. In the case of a hard spring water in which the carbon dioxide reached to nearly 300 c.cs. per litre, the determinations of this gas before and after keeping showed differences of as much as 2 c.cs., although the atmospheric nitrogen and oxygen determinations were similar, and indicated that no fermentation had gone on therein during the time of keeping it. In consequence of this, I have avoided, when possible, the presence of any large quantity of carbon dioxide, and have employed sodium carbonate only, when it was necessary to add a carbonate to my test solutions.

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* C. S. J., 1881, 100.

The errors of the gas analysis apparatus are very small, and need not be discussed, since I have dealt with them in the Paper already referred to, describing the earlier form of the instrument.

It will be seen from the foregoing remarks that, although the method is open to several sources of error, it is possible to keep the total error within such narrow limits that valuable results may be obtained by it. But in order to effect this, it is necessary to observe certain precautions in carrying out some of the steps in the method, and to these precautions I will now briefly refer.

THE PREPARATION AND ANALYSIS OF THE SOLUTIONS AND DILUTIONS.

In the first place the tap-water employed was that supplied to Dublin from the Vartry Waterworks. It is a good upland surface water, and has proved a valuable one for the purposes of my experiments, since it contains extremely small quantities of dissolved matters, the total solids being usually not more than four parts per 100,000 of water. It, however, invariably contains small quantities of peaty colouring matter, and for this reason I have sometimes found it necessary to use pure distilled water instead. The water was drawn from a large cistern holding nearly 400 gallons.

When making up a long series of dilutions for observation, it has, of course, been impossible to determine the gases in each member of the series just before bottling, since the time required for so many analyses would be so considerable that it would be impossible to prevent serious changes of temperature, and also, in all probability, fermentative changes, especially if sewage-water happened to be the subject of experiment, and the final results would therefore not be comparable. When dealing, therefore, with a series of dilutions at the commencement of an experiment, I have determined the dissolved gases and inorganic nitrogenous bodies in the lowest dilutions, and in the tap water employed for making the dilutions, only, and calculated, from the data obtained, the quantities of dissolved gases and inorganic nitrogenous substances for all the other dilutions made up. I need scarcely remark that at the conclusion of an experiment each member of the series of dilutions has been in every case directly analysed.

I have adopted a similar method of preparation for all the dilutions I have experimented with. The basis of each series of dilutions has been either undiluted sewage-water, or a strong solution of other substances of known composition and strength. Five litres, at least, of the lowest dilution have been made, and aërated by violent agitation with air in a large glass vessel fitted with a glass tap. After the aëration the solution has been allowed to rest for about fifteen minutes, to allow air-bubbles to rise to the surface and escape.

Two or more bottles have been carefully filled, and allowed to stand unstoppered for a few minutes, until again all air-bubbles have escaped. All the bottles, with the exception of one, were then carefully stoppered, and placed neck downwards in distilled water. The one left unstoppered was at the same time transferred to the gas analysis apparatus, and the volume of the liquid required for the analysis then drawn from it into the burette of the apparatus, and thence passed into the laboratory flask, and boiled in vacuo.

Immediately this had been done, the preparation of the remaining dilutions required is proceeded with in an exactly similar manner, except that portions of them were not reserved for analysis.

When all the dilutions have been made, five litres of tap-water were placed in the same glass vessel, and agitated with air just as in the case of the dilutions. The water after aëration is drawn off into bottles and preserved in the ordinary way, a portion, as in the case of the lowest solution, being transferred to the gas analysis apparatus. With the aid of an assistant, the analysis of the lowest dilution and the preparation of all the required dilutions may be completed within two hours, when the duration, bottling, and analysis of the tap-water may be proceeded with without delay.

The chief point of importance to be attended to in the preparation of these dilutions is that of temperature: it should be the same for each dilution. This is not difficult to accomplish when the tap-water is drawn from so large a cistern as that which has furnished my supply. I have also taken the precaution of tying up the ball-cock of the cistern when making up the dilutions.

The complete aëration of the dilutions is also of importance; but with a good tap-water such as I have employed, this condition can be attained without difficulty.

In all my experiments I have endeavoured to keep the variation of temperature from that obtaining at their commencement within as narrow limits as possible, and as a result of this I have found it unnecessary to make any correction for expansion or contraction of the liquid arising from change of temperature, the errors arising therefrom being very small in comparison with those from other sources; thus the maximum difference between the initial and final temperature of any of the experiments I shall quote in this Paper has been within 12° C., viz., from 8° C. to 19° C. A litre of water, on rising from 8° C. to 19° C., would increase (according to the data given in Muir and Morley's edition of "Watt's Dictionary," vol. iv., p. 861) in volume by 1·409 c.cs. Such an alteration in volume, it will be seen from the details of my experiments, gave rise to so small an error in comparison with others which affected them that it was thought unnecessary to make any correction for it.

The errors arising from the tendency to disengagemant of the dissolved gases on variation of temperature would of course be very large, and in fact would render the results valueless, had not the precaution already described been taken to prevent the escape of the disengaged gases from the bottle in which the solution was kept.

The conditions which give rise to the maximum disengagement of gases from liquids kept in bottles, in the manner I have already explained when describing the method of experiment adopted, and apparatus employed for this investigation, are, first, a considerable rise of temperature above the initial point, during which the liquid will expand, and small quantities of it be forced out of the bottle between the neck and the stopper, followed by a considerable fall, when the liquid will contract, and, if the stopper be well ground, a small space will be formed in the bottle containing gases previously dissolved, and will be more or less steadily maintained, since the bottle is immersed in water, neck downwards, so long as the temperature remains below the

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maximum point to which it was formerly raised. The relation between the quantity of each gas disengaged in this way to that remaining in solution will practically vary with the temperature, according to Henry's Law.

As a practical illustration of the influence of variation of temperature upon solutions kept under the conditions described, I may here give an extreme case, viz. an experiment with tap-water kept for a period of fourteen months.

This experiment was started on the 2nd February, 1893, when the tap-water before bottling was violently shaken up with air in a large vessel. After this operation the water was allowed to stand until quite free from air bubbles. Its temperature was then found to be 10° C. A bottle was carefully filled with a portion of the aërated water, another portion being immediately afterwards transferred to the laboratory flask of the gas analysis apparatus. On April 3rd of the following year the contents of the bottle were examined. A bubble of gas, about 6 c.cs. in volume, was found to have been formed. The gases in the bubble were collected over fully aërated water, and immediately afterwards transferred to the laboratory vessel of the gas analysis apparatus, measured, and analysed; the water in the bottle was not examined until next day, in order to allow time for the distilled water, which had replaced the disengaged gases, to diffuse equally through it. During this time, it need scarcely be said, the bottle was kept immersed in water.

The temperature at the conclusion of the experiment was 13·8°C.

The results of the analysis of the disengaged gases were as follows:—

Total volume at 0° C. and 760 mm. Bar, ...	5·8414 c.cs.
Volume of oxygen „ „	1·0058
Volume of nitrogen	4·8356
Volume of carbon dioxide	0

The capacity of the bottle was 2,530 c.cs. Dividing the volumes of oxygen and nitrogen by 2·53 we get the volumes of these gases disengaged, per litre of water, at the time of the conclusion of the experiment. These volumes are:—

Oxygen	0·40 c.cs.
Nitrogen	1·91

The results of the analysis of the gases* dissolved in the water at the commencement and conclusion of the experiment are given in the following Table:—

—	CO_2.	O_2.	N_2.	N as NH_3	N as N_2O_5
At commencement - - - -	4·04	7·8	15·60	0	0·0001
At conclusion - - - - -	4·94	6·23	13·60	0	0·0008
Correction for disengaged gases -	0	0·40	1·91	—	—
Corrected volumes - - - -	4·94	6·63	15·50	—	—
Differences - - - - -	+0·90	−1·17	−0·10	—	+0·0007

No correction was made for the distilled water introduced into the bottle when collecting the disengaged gases.

The changes in volume of the carbon dioxide and oxygen shown in the above Table were no doubt due to the fermentation of small quantities of peaty colouring-matter which the tap-water contained, and not to experimental errors. This explanation is supported by the increase quantity of nitrate found in the water after keeping.

The gaseous nitrogen, however, remained unchanged in volume during the period of keeping, and the difference between the volume of this gas found before and after keeping indicates the probable value of the total error from the two distinct sources mentioned above.

Before leaving the consideration of errors due to variation of temperature of the solutions during the time of keeping them, I ought perhaps to point out that a disengagement of dissolved gases on rise of temperature is more or less completely prevented under the ordinary conditions of my experiments, since a considerable pressure was always kept up in the bottles when the temperature was rising, by keeping them resting with their full weight upon their stoppers.

This I have generally found sufficient to prevent the stoppers from becoming too freely loosened by the expanding force of the water under the influence of rise of temperature. I should add that care has been taken to guard the solutions against any serious daily variations of temperature, and the precaution of re-tightening the stoppers from time to time has also been taken.

PART I.—EXPERIMENTS WITH EASILY FERMENTABLE MATTERS.

As I have already explained when describing the method of experimenting adopted, the experiments which I have now to record have for the most part been carried out with sets or series of dilutions, varying in strength, of comparatively strong solutions of polluted waters, such as sewage-water, or of other fermentable substances, including those which ferment with ease, and those which ferment with difficulty.

The details and results of the experiments are given in full in Tables, a separate Table to each set or series of experiments. Each Table, therefore, furnishes a fairly complete view of the nature and amount of the chief substances produced by the action of the mixed organisms natural to the solution or dilution during a fermentation, carried on under conditions varying within narrow and well-defined limits, as well as the quantity of oxygen consumed in the process.

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* Volumes of the gases are expressed in c.cs., at N.T.P., per litre of water.

The information given in these Tables will, therefore, be found sufficiently full to render them self-explanatory.

But it will be necessary to discuss the results in some of the Tables at some length in order to indicate the typical results, which the method of experimenting employed can afford, and the general conclusions which can be drawn therefrom. The remaining Tables will be found to furnish additional experimental results, all tending to confirm those specially referred to.

It will be convenient to discuss, in the first place, the experiments with easily fermentable organic matters; and this I now propose to do, not necessarily in chronological order, but as they best illustrate the points which have to be considered.

My first definite series of experiments was commenced on November 5th, 1891, and they were made with a sample of raw sewage collected from a main sewer at Monkstown, a residential suburb of Dublin. The sample of sewage was filtered through ordinary filter-paper to separate the matters in suspension as much as possible, and aërated, and the following dilutions were made from it with tap-water:—one volume of filtered sewage to 9, 19, 29, 39, 49, 59, 69, 79, 89, and 99 volumes of tap-water.

In the following, and all succeeding Tables giving the details and results of experiments, the dissolved gases are expressed in c.cs., at 0° C., and 760 mm. bar., and the inorganic nitrogen in fractions of a gramme, per 100 c.cs., of solution.

Under the columns headed I. and II. are given the results of analysis, before and after fermentation, respectively.

SERIES I.—COMMENCED 25TH NOVEMBER, 1891.

TABLE I.—*The Volume of Gases, and the Weights of Ammoniacal and Nitric Nitrogen, in the Mixtures of Sewage and Tap-Water, employed in Series I. of Experiments, before and after Fermentation.*

[The gases are expressed in c.cs., measured at 0° C., and 760 mm. bar.; the other constituents, as parts by weight, per 1000 c.cs. of liquid.]

Date of con-conclusion of Experiment.	Mixture.	CO_2 I.	CO_2 II.	O_2 I.	O_2 II.	N_2 I.	N_2 II.	N as NH_3 I.	N as NH_3 II.	N as N_2O_5 I.	N as N_2O_5 II.
1892.											
January 21	1 in 100	4·32	6·70	8·03	2·54	15·96	15·60	0·00062	0·00	0·00010	0·0010
	Differences - -	+2·38		−5·49		—	—	−0·00062		+0·009	
February 3	1 in 90	4·43	7·15	8·02	1·68	15·96	15·61	0·00067	0·00	0·0001	0·0012
	Differences - -	+2·72		−6·34		—	—	−0·00067		+0·0011	
February 4	1 in 80	4·51	7·64	8·02	0·77	15·90	15·60	0·00077	trace.	0·0001	0·0012
	Differences - -	+3·13		−7·25		—	—	−0·00077		+0·0011	
February 4	1 in 70	4·66	7·94	8·00	0·62	15·96	15·60	0·00086	0·00012	0·0001	0·0012
	Differences - -	+3·28		−7·38		—	—	−0·00074		+0·0011	
February 5	1 in 60	4·81	9·18	8·00	0·48	15·97	15·68	0·0010	0·0008	0·0001	0·0008
	Differences - -	+4·37		−7·52		—	—	−0·0002		+0·0007	
February 5	1 in 50	5·09	10·23	7·98	0·00	15·97	15·55	0·0012	0·0012	0.0001	0·0006
	Differences - -	+5·14		−7·98		—	—	−0·00		+0·0005	
February 5	1 in 40	5·46	11·55	7·96	0·00	15·99	15.51	0·0015	0·0019	0·0001	0·0004
	Differences - -	+6·09		−7·96		—	—	+0·0004		+0·0003	
February 6	1 in 30	6·08	13·11	7·92	0·00	15·98	15·79	0·002	0·0032	0·0001	0·00
	Differences - -	+7·03		−7·92		—	—	+0·0012		−0·0001	
February 11	1 in 20	7·31	18·56*	7·85	0·00	15·99	15·80	0.003	0·005	0·0001	0·00
	Differences - -	+11·25		−7·85		—	—	+0·002		−0·0001	
February 11	1 in 10	11·03	26·40*	7·63	0·00	16·07	20·09†	0·006	0·0068	0·00	0·00
	Differences - -	+15·37		−7·63		—	—	+0·000		0·00	
February 15	Tap-water - -	3·58	3.45	8·07	8·00	15·95	15·82	0·00	0·00	0·00010	0·001

REMARKS.—Nitrous acid was not detected in any of the mixtures after fermentation. Mixtures 1/100 to 1/50 were quite inodorous after fermentation. 1/40 emitted an odour like that of rain-water. 1/30, 1/20, and 1/10 were very offensive.

The foregoing Table illustrates very clearly the results which are obtained by the fermentation of dilutions of the same sewage-water under conditions gradually varying from those in which the atmospheric oxygen is in excess, relatively to the fermentable matters, to those in which the fermentable matters are in excess.

Solutions 1/100 to 1/80 afford an illustration of the influence of an excess of oxygen. In each of these solutions the fermentation has extended to the complete oxidation of the ammonia in the admixed sewage. In solutions 1/70 and 1/60 the conditions were evidently evenly balanced, for both a little free oxygen and a little ammonia were left in each. In solutions 1/50 and 1/40 the influence of gradually increasing quantities of fermentable matters in proportion to atmospheric oxygen is indicated by increasingly small quantities of nitrogen becoming oxidised,

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* Each of these volumes include small quantities of SH_2.

† This volume includes CH_4 and H. The volume of these gases was not determined owing to an accident during analysis.

Dr. Adeney. — — and by increasingly large quantities of ammonia left unoxidised. In solutions 1/30 and 1/20 we see that no oxidation whatever of nitrogen took place, and we notice for the first time that the volume of carbon dioxide begins to show a slight decrease relatively to the volumes of the gas formed in the more dilute solutions after fermentation. This is still more noticeable in the strongest solution 1/10. In this connection it is of interest to note that, simultaneously with the relative decrease in volume of carbon dioxide formed, bodies having offensive odours begin to make their appearance.

If we examine the contents of the Table a little more closely, we shall find that a number of important conclusions may be drawn as to the quantitative relationships existing between the amounts of atmospheric oxygen, and of fermentable matters originally present in the solutions on the one hand, and the products of fermentative changes on the other. These relationships become more apparent when each set of differences between the analytical results given in the Table for each solution are multiplied so as to make them comparable with one another. When so multiplied, the numbers may also be taken to represent the results which would have been obtained by experimenting with undiluted sewage, had that been possible, under the respective conditions represented by each dilution. In the following Table are given the products obtained by multiplying the differences in Table I. as described:—

TABLE II.

Solution.	Multiplier.	1. CO_2	2. N as NH_3	3. N as N_2O_5	4. O in c.cs. equiv. to N_2O_5	5. Sum of 1 and 4.	6. Vol. of O. absorbed.
1/100	100	+238	−0·062	+0·09	287	525	549
1/90	90	+245	−0·060	+0·099	316	561	571
1/80	80	+254	−0·062	+0·088	281	535	580
1/70	70	+230	−0·052	+0·077	245	475	517
1/60	60	+262	−0·012	+0·042	134	396	451
1/50	50	+257	0·0	+0·025	80	337	399
1/40	40	+244	+0·016	+0·012	38	282	318
1/30	30	+211	+0·036	0·0	0	211	238
1/20	20	+225	+0·04	0·0	0	225	157
1/10	10	+154	+0·008	0·0	0	154	76

The volume of oxygen given in column 4 as equivalent to the weights of N_2O_5 in the preceding column have been added for convenience of comparison; they have been calculated from the equation:—

$$2NH_3 + 4O_2 = N_2O + 3H_2O.$$

This equation gives 3·19 c.cs., oxygen at N.T.P. as the volume required to oxidize 0·001 grammes nitrogen as NH_3 to N_2O_3.

Column 5 gives the sum of the volumes of carbon dioxide actually formed, and of oxygen theoretically equivalent to the nitric acid formed, and have also been added for comparison with the volumes of oxygen actually consumed.

The figures in the above Table, when allowance is made for errors, show that in the case of each of the solutions 1/100, 1/90, 1/80, in which the fermentation extended to the complete oxidation of ammonia, the quantities of carbon dioxide and nitric acid formed, and the volume of oxygen absorbed, were practically directly proportional to the quantities of fermentable matter originally present in them.

We also see that in all the other solutions down to 1/40, in which the sewage matters were gradually increased in relation to the dissolved oxygen, the volume of carbon dioxide formed was still directly proportional to the quantities of sewage matters originally present therein, and that the first effect of gradually increasing the proportion of sewage matters was the oxidation of relatively smaller quantities of ammonia; and as the proportions of sewage matters were still further increased, the ammonia began to be formed, instead of oxidized.

In the solution 1/40 the proportion of sewage-matters to dissolved oxygen was evidently pushed to its maximum. That is to say, the dissolved oxygen present was only just sufficient for the completion of the first stage of the fermentation of the organic matters, viz., the breaking down of the organic matters into carbon dioxide, water, and ammonia.

Hence, from the results of these experiments, if the fermentation of sewage-matters really takes place in the two stages already referred to, we may tentatively conclude that when the dissolved oxygen is present in sufficient quantity for the completion of both stages, the quantities of carbon dioxide and nitric acid formed, and the volume of the dissolved oxygen absorbed, are directly proportional to the quantity of sewage-matters originally present.

If, however, the oxygen be not in sufficient quantity for the completion of both stages, but that of the first only, then the volume of carbon dioxide formed is still directly proportional to the quantities of sewage-matters originally present, and the oxidation of ammonia will or will not proceed according as there happens to be an excess or not of oxygen over and above that required for the first stage of fermentation.

In the solutions 1/30, 1/20, and 1/10, we have an insufficient quantity of dissolved oxygen for the completion of the first stage of fermentation. We then see a secondary, or an aërobic, fermentation sets in, in which the fermentation of the organic matter has been proportionally less and less complete as the quantity of sewage-matter increased. No simple relation between the carbon dioxide formed, and the quantity of sewage-matter originally present, is apparent under this condition.

We may go further, and sum up the results given in the two Tables in a definite quantitative form, thus:—1,000 volumes of the sample of sewage-water experimented with required 580 volumes of atmospheric oxygen, with a probable error of 15 volumes, for the complete fermentation of the fermentable matters, 280 volumes of which were required for the completion of the first stage, and 300 volumes for the second stage of fermentation. Or we may put it in another way, and state that that when 1 volume of the sewage-water was mixed with 39 volumes of good river-water, fully aërated and fairly pure, at winter temperature, the oxygen dissolved in the river-water was sufficient for the first stage of fermentation; and, when mixed with 69 volumes, the supply of dissolved oxygen was sufficient for both stages of fermentation of the admixed sewage-matters. The atmospheric nitrogen determination for the solutions 1/100 to 1/40 inclusive show greater differences than will be found usual. These may possibly not be due to experimental errors, but rather to "fixation" of atmospheric nitrogen during fermentation (see p. 587).

It should be noted that the tap-water used for diluting the sewage-water suffered but little, any, change during the period of keeping.

Although the results afforded by this series of results were definite enough to warrant the conclusions I have formulated, they could not be considered as constituting a sufficient basis for extending these conclusions to polluted and natural waters generally.

Other waters, whether polluted with sewage-matters or vegetable matters such as peat, might contain fermentable substances of different composition and organisms of different chemical functions; and such waters, when similarly examined, might give rise to results which might lead to different conclusions. It was therefore necessary to extend my observations to polluted and natural waters differing widely in character from one another.

I first, however, made some further experiments with other samples of sewage-water taken from the same locality as that from which the sample employed in my first series of experiments was taken. These confirmed the results I have already given, and need not be recorded here.

As examples of results obtained with sewage-water from quite a different locality, I will give those of two series of experiments with two samples, for which I was indebted to the kindness of Mr. J. C. Melliss, C.E., of London. Both samples were taken on June 21st, 1893, from the Richmond Main Drainage Works, near London, one being of raw sewage before treatment, and the other of sewage-water after clarification with lime and sulphate of alumina, and a very careful filtration through one of the gravel filter-beds with which the works are furnished. Each sample was an average of portions collected hourly from 6 a.m. to 6 p.m.

The raw sewage was filtered and aërated, and the following dilutions were made as before:—1 volume of raw sewage to 9, 19, 39, and 79 volumes of tap-water. The particulars of the experiments are given in the subjoined Table:—

SERIES II.—COMMENCED 24TH JUNE, 1893.

TABLE III.—*Experiments with Sewage and Tap-water.*

Date of conclusion of Experiment.	Solution.	CO_2		O_2		N_2		N as NH_3		N as N_2O_5		Remarks.
		I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	
1893.							*					
July 25	1 in 10	23·35	29·44	6·42	0·00	13·41	20·83	0·0045	0·0047	0·00009	0·00	Solution very offensive after fermentation.
	Differences	+6·09		−6·42		...	...	+0·0002		−0·00009		
July 26	1 in 20	14·21	19·78	6·44	0·18	13·41	13·49	0·00225	0·0025	0·00009	0·00	Solution free from odour after fermentation.
	Differences	+5·57		−6·26		...	...	+0·00025		−0·00009		
July 26	1 in 40†	9·64	12·45	6·46	3·16	13·41	13·49	0·001125	0·00115	0·0001	0·0001	Ditto.
	Differences	+2·81		−3·30		...	...	+0·000025		0·00		
Sept. 1	1 in 80	7·36	9·17	6·46	2·12	13·41	13·34	0·00056	0·00	0·0001	0·0008	Ditto.
	Differences	+1·81		−4·34		...	...	−0·00056		+0·0007		

It may be remarked that nitrous acid was not detected in any of the solutions of this series of experiments.

* This volume includes N, CH_4, and H, disengaged during fermentation, but they were not separately determined.

† The remainder of this solution was, immediately after examination, re-aerated, analysed, and set aside to ferment till September 1st, when it was re-examined, with the following results:—

1893												
	...	11·31	11·99	5·78	1·44	12·96	12·99	0·00115	0·00	0·0001	0·0017	...
Sept. 1.	Differences	+0·68		−4·34		...	...	−0·00115		+0·0016		

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Multiplying each set of differences as before we get:—

TABLE IV.

Solution.	Multiplier.	1. CO	2. N as NH_3	3. N as N_2O_5	4. O in c.cs. $=N_2O_5$	5. Sum of 1 and 4.	6. Vol. of O_2 absorbed.
1/10 - -	10	+ 61	+0·002	0·0	0·0	61	64
1/20 - -	20	+111	+0·005	0·0	0·0	111	123
1/40 (1st stage)	40	+112	+0·001	0·0	0·0	112	132
1/40 (2nd stage)	40	+ 27	−0·046	+0·064	204	231	174
1/80 - -	80	+145	−0·015	+0·056	179	324	347

We see from the above Table that in solution 1/10 the dissolved oxygen was not in sufficient quantity for the first stage of fermentation; hence putrefactive fermentation had occurred.

But in the two following solutions it was; and in each the volume of carbon dioxide formed and the volume of oxygen absorbed were directly proportioned to the quantity of fermentable matter originally present therein.

We further note that the time allowed for fermentation, 1/20 and 1/40, was only sufficient for the carbon fermentation, and that in neither had nitrogen fermentation commenced. We may therefore note this result, as in this experimentfully aërobic conditions were maintained throughout, and yet no nitrification occurred; we may consider it as strong evidence in favour of the view that the fermentative changes really occur in two distinct stages—a view which other observers have maintained, and which I have assumed as true in the earlier part of the Paper.

It is important to note that the oxidation of ammonia to nitric acid is accompanied in solution 1/40 and inferentially in 1/80, by the formation of relatively small quantities of carbon dioxide.

The gas so formed was probably derived, as I shall show by later experiments, from the small quantities of oxidized organic substance which, as we shall find later, may under certain conditions be formed from the sewage-matters during the first stage of fermentation. The collected results for solution 1/40, and those for 1/80, show that when both stages are complete the quantities of carbon dioxide and nitric acid formed, and the volume of oxygen absorbed, were practically directly proportional to the quantity of fermentable matter originally present.

Putting the results in a quantitative form as before, we may say that 1,000 volumes of sewage-water required 306 to 347 volumes of atmospheric oxygen for the complete fermentation, 125 to 132 volumes being required for the first stage, and 181 to 215 for the second stage.

The filtered sample of sewage from the Richmond Works, when similarly examined, gave the following results:—

SERIES III.—COMMENCED JUNE 24TH, 1893.

TABLE V.—*Experiments with Sewage-water, which has been filtered through gravel filter-beds, and tap-water.*

Date of conclusion of Experiment.	Solution.	CO_2		O_2		N_2		N as NH_3		N as N_2O_3		N as N_2O_5	
		I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
1893													
July 18	1 in 2	77·50	83·85	6·38	0·00	13·58	13·70	0·0085	0·0075	0·0018	0·0016	0·003	0·0045
	Differences,	+6·35		−6·38		..	...	−0·001		−0·0002		+0·0015	
July 19	1 in 4	41·29	44·00	6·43	0·00	13·58	13·54	0·00425	0·0030	0·0009	0·00003	0·00155	0·0028
	Differences,	+2·71		−6·43		...	..	−0·00125		−0·00087		+0·00125	
July 20	1 in 8	23·18	24·80	6·45	0·00	13·58	13·43	0·00213	0·0005	0·00045	0·00	0·000825	0·0028
	Differences,	+1·62		−6·45		...	...	−0·0016		−0·00045		+0·00198	
July 24	1 in 16	14·12	15·11	6·46	3.41	13·58	13·54	0·00107	0·00025	0·000225	0·00	0·000402	0·0015
	Differences,	+0·99		−3·05		...	...	−0·00082		−0·000225		+0·001	

REMARK.—All the solutions were quite free from odour after fermentation.

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On multiplying each set of differences, so as to make them comparable one to another, and to the undiluted sample, we get:—

TABLE VI.

Solution.	Multiplier.	1. CO_2	2* N as N_2O_3 oxidised to N_2O_5	3. $O_2=N_2O_3$ oxidised.	4.† N as N_2O_5 from NH_3	5. $O_2=NH_3$ oxidised.	6. Sum of 1, 3, and 5.	7. Vol. of O_2 absorbed.
1/2	2	12·7	0·0004	0·32	0·0026	8·29	21·31	12·8
1/4	4	10·8	0·00348	2·78	0·0015	4·79	18·37	25·7
1/8	8	13·0	0·0036	2·86	0.0122	38·92	54·80	51·0
1/16	16	15·8	0·0036	2·88	0·0124	39·56	58·24	48·8

In the results given in these two Tables we have still further evidence that the volume of oxygen absorbed is practically proportional to the quantity of matters fermented; but in them we have also a more definite indication of the chemistry of at least one phase of nitrification than is observable in those of the two preceding series of experiments.

It may be taken for granted, I think, from the fact that nitrification had already been well established in this sample of filtered sewage-water before the commencement of my experiments, and from the general character of the results obtained, that the first stage of fermentation had been completed during the process of filtration to which it had been subjected at the Works from which it had been collected.

We have therefore, in this series of experiments illustrations of the second stage of fermentation or true nitrification only; and it fortunately happens that the dilutions made up were just of sufficient strength to clearly illustrate the chemical changes which accompany nitric fermentation in polluted waters during their passage through land or artificial filters.

It will be observed, on looking over the results given in the two foregoing Tables, that a fermentation of both nitrous acid and ammonia into nitric acid took place in each solution; that the fermentation of the nitrous acid in solutions 1/2 and 1/4 was incomplete, but complete in the remaining solutions, and that the ammonia was not completely oxidized in any of the solutions; and finally, that a decided quantity of carbon dioxide was formed during fermentation in each solution. This last noted product becomes of interest, and I may say of importance, when considered in relation to the recent researches of Dr. Munro, Professor P. F. Frankland and Mrs. G. C. Frankland, Mr. Warrington, and M. Winogradsky, already referred to, on the nitrification of ammonia in the absence of organic matters. These observers have all shown that the product of fermentation of ammonia in the absence of organic matter is invariably nitrous acid; and Winogradsky has supplied quantitative proof that the nitrous organism produces organic matters from inorganic materials, about thirty-five parts of nitrogen being oxidized for one part of carbon assimilated from ammonium carbonate. In the above Tables we see that the nitric fermentation therein illustrated is accompanied by the formation of very distinct volumes of carbon dioxide, just as was noted in reference to the second experiment recorded in Table III. The question arises, what was the nature of the organic matter from which this gas was derived.

From the next series of experiments, which I shall have to describe, we shall find evidence which goes to show that the organic matters which undergo change during a second stage fermentation of the character above illustrated, have themselves been formed during a first-stage fermentation under aërobic conditions.

The results recorded in Table V. for solution 1/4 require special reference, as they appear to be exceptional when compared with those afforded by the other solutions of the series.

Thus, relatively less carbon dioxide was formed in it; and the total inorganic nitrogen found after fermentation was decidedly less than that present before fermentation, the quantities being 0·00583 and 0·00670 parts per 1,000 respectively. On the other hand, the volume of dissolved oxygen actually absorbed was relatively similar to that absorbed in the other solutions.

The exceptional results here apparent are not, I consider, due to experimental errors, they are rather to be ascribed to a difference of type, or phase, of a second-stage fermentation.

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[*] The numbers in this column have been calculated on the assumption that N as N_2O_3, shown to have been lost during fermentation, was completely oxidized to N_2O_5; and the figures in the next column have been calculated on the assumption that the oxidation of the N_2O_3 took place according to the equation $N_2O_3+O_2=N_2O_5$.

This gives 0·8 c.cs. oxygen required to oxidise 0·001 grammes N as N_2O_3 to N_2O_5.

[†] The numbers in this column give the N_2O_5 less the loss of N_2O_3 during fermentation, and it is assumed that these quantities were derived from ammonia. The numbers in the next column have been calculated on this assumption, as already explained. These four columns have been added simply for the purpose of approximate comparison.

It will be observed that the total N as NH_3 and N_2O_3 lost in the case of each solution, except solution 1/4, is nearly equal in quantity to the N as N_2O_5 formed.

Dr. Adeney. In the other solutions of this series we have apparently one and the same type of nitrogen fermentation taking place, viz., a fermentation of NH_3 and N_2O_3 into N_2O_5, accompanied by a fermentation of organic matter. In the solution under discussion we have also this type of fermentation occurring, but, apparently, in addition, another type, viz., the oxidation of ammonia, and possibly also of nitrous acid to nitric acid, accompanied by a fixation of small quantities of inorganic materials, presumably to form organic matter, as Winogradsky has shown takes place in the nitrous fermentation of ammonia in the absence of organic matter.

That a number of variations are possible during the fermentation of NH_3 and N_2O_3 in the presence of organic matters that have undergone the first stage of fermentation, I shall show by further experiments.

Regarding the method of examination, illustrated by these experiments, simply as an analytical probe, it is quite evident that it affords the means of differentiating the character of fermentable matters in waters, and approximately estimating their amount, to a degree quite beyond the power of any other method. Thus, when the samples of raw and filtered sewage water were examined by the methods commonly used, the following results were obtained :—

Constituents expressed as parts per 1,000.

	Untreated Sewage-Water.	Filtered Sewage-Water.
Free ammonia - - - . - - -	0·0475	0·017
Albuminoid ammonia - - - - - -	0·005	0·0012
Oxygen absorbed from standard $KMnO_4$ acting in the cold for three hours - - - -	50·2 c.cs.	16·2 c.cs.

It is impossible, of course, to draw any conclusion as to the character of the organic matters in either sample from the above results. They do not even give any definite idea of the actual quantities of the organic matter in the samples, neither do they afford the means of estimating the influence which such liquids would exert in river-water when discharged into it. While, on the other hand, the results afforded by the experiments of Series II. and III., above described, give complete answers to each of these points. They show that, on the one hand, the untreated sewage-water underwent a first-stage fermentation before true nitrification, and therefore contained matters which would set up putrefaction if the supply of atmospheric oxygen to all parts were restricted, and that on the other hand, the filtered sewage-water did not, but nitrification alone, and that therefore putrefaction was impossible in the liquid, even when the supply of dissolved oxygen was restricted. They further show the exact volumes of atmospheric oxygen required for the complete fermentations in the untreated water, and that required for the complete fermentation in the filtered water, giving at the same time the quantities and character of the products of fermentation.

The next series of experiments which I have to describe were made with solutions of definite chemical compounds, and it will, I think, be also of advantage to discuss them, not in their chronological order, but in such a way as may best serve to bring out the points I am anxious to establish in this research.

I will therefore first describe a series of experiments carried on with a solution of asparagine and crystallized potassium sodium tartrate. A strong solution was made up containing 0·066, and 0·141 grammes of these bodies, respectively; also 0·1 gramme of potassium phosphate per litre of solution; only two dilutions were made from this, it being determined to commence the experiments with a considerable quantity of each solution in several bottles, and if necessary, after determining the products of a fermentation, to re-aerate and analyse, and to put up again in smaller bottles for a further fermentation. It was hoped by this means to gain, more especially, definite information on the question whether ammonia was formed during the first stage fermentation of a nitrogenous substance, in the continued presence of an excess of dissolved oxygen or not.

There were other reasons for making this modification in detail of the method of examination which will appear as the results of the experiments are considered.

The full particulars of these experiments are given in the subjoined Tables VII. and VIII.

SERIES IV.—COMMENCED MARCH 6TH, 1894.

TABLE VII.—*Experiments with Asparagine and Sodium Potassium Tartrate.*

Solution A contained 0·066 grammes asparagine, } per litre.
0·141 „ sodium potassium tartrate, cryst., } per litre.
0·1 „ potassium phosphate. } per litre.

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Nature of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5	Remarks.
	1894								
1	March 6	Solution A, as above (in tap-water) - -	11·21	7·86	15·93	0·0	0·0	0·0001	
	„ 12	Same after fermentation - -	26·73	0·05	16·13	0·0093 ?	0·0	0·0	Liquid very turbid, but free from odour.
		Differences -	+15·52	−7·81	—	+0·0093 ?	—	—	
2	„ 12	Remainder of preceding solution, after fermentation, re-aerated, = A′ - - -	26·62	7·36	15·14	0·0095 ?	0·0	0·0	
	„ 13	A′ after fermentation - - I.	37·16	1·52	15·30	0·0108 ?	0·0	0·0	Ditto.
	„ 14	Another bottle of A′ after fermentation from March 12 - II.	40·15	0 05	15·16	0·0102 ?	0·0	0·0	Ditto.
		Differences I.	+10·54	−5·84	—	+0·0013 ?	—	—	
		Differences II.	+13·53	−7·31	—	+0·0007 ?	—	—	
3	„ 14	Remainder of solution A′ (March 14) diluted with equal volume of distilled water and aerated = A′/2 - - -	20·62	7·81	16·11	0·0032	0·0	0·0	
	„ 19	Same after fermentation - I.	32·21	1·72	15·92	0·0045	0·0	0·0	Faint sour odour, turbid.
	„ 19	Another bottle of A′/2 after fermentation II.	32·01	1·56	15·89	0·0038	0·0	0·0	Ditto.
		Differences I.	+11·59	−6·09	—	+0·0013	—	—	
		Differences II.	+11·39	−6·25	—	+0·0006	—	—	
4	„ 19	Remainder of liquid from two preceding analyses, mixed and aerated - -	29·06	7·56	15·60	0·0030	0·0	0·0	
	April 12	Same after fermentation - -	36·75	0·00	15·40	0·0056	0·0	0·0	No distinct odour.
		Differences -	+ 7·69	−7·56	—	0·0026	—	—	
5	„ 12	Remainder of preceding solution re-aerated - -	31·42	7·04	13·98	0·004	0 0	0·0	
	August 1	Same after fermentation - -	35·22	0·0	14·10	0·0041	0·0015	0·0	Quite free from odour.
		Differences -	+ 3·80	−7·04	—	+0·0001	+0·0015	—	
6	„ 1	Remainder of preceding solution diluted with an equal bulk of distilled water and aerated -	17·033	6·11	12·67	0·0022	0·0009	0·0	
	1895								
	Jan. 4	Same after fermentation I.	16·69	0·07	12·55	0·0	trace	0·002	
	„ 14	Another bottle of same after fermentation II.	16·79	0·05	12 63	0.0	0·00016	0·00204	
		Difference I.	− 0·34	−5·94	—	−0·0022	−0·0009	+0.002	
		Differences II.	− 0·24	−5·96	—	−0·0022	−0·00074	+0·00204	

TABLE VIII.—*Experiments with solution A diluted with tap-water.*

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Nature of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5	Remarks.
	1894.								
1*a*	March 6	Solution A from Table VII., diluted with tap-water in the proportion of 1 : 9 vols. - -	4·65	7·86	15·93	0·0	0·0	0·0001	
	,, 15	Same after fermentation - -	9·32	4·52	15·75	0·0008	0·0	0·0001	Slightly turbid. no odour.
		Differences -	+4·67	–3·34	—	+0·0008	—	—	
2*a*	,, 15	Remainder of preceding solution aerated - -	9·05	7·35	15·64	0·0008	0·0	0·0001	
	May 17	Same after fermentation - - -	12·28	2·06	15·47	0·0	0·0	0·0015	
		Differences -	+3·03	–5·19	—	–0·0008	—	+0·0014	
3*a*	March 6	Solution A from Table VII., diluted with tap-water in the proportion of 1 : 19 vols., I.	4·29	7·86	15·93	0·0	0·0	0·0001	
	,, 20	Same after fermention, - - II.	6·86	5·63	15·94	0·0008	0·0	0·0001	
		Differences -	+2·57	–2·23	—	+0·0008	—	—	
4*a*	,, 20	Remainder of preceding solution immediately transferred to a smaller bottle, and after further fermentation again analysed							
	April 30		8·04	4·02	15·86	trace	0·00048	0·00042	
		Differences (from II.) - -	+1·18	–1·63	—	–0·0008	+0·00048	+0·00032	

Continuing the train of thought suggested by the three preceding series of experiments, we may note in the first instance that the experiments recorded in the Tables VII. and VIII. afford further evidence that the fermentation, which may take place in a natural water containing unfermented matters in solution, under aërobic conditions, does so in two distinct stages.

That ammonia, and not nitrous or nitric acid, is formed during the first stage of fermentation of nitrogenous organic matters, even in the continued presence of an excess of dissolved oxygen, is clearly proved by experiments 1, 2, and 3, in Table VII., and by 1*a* and 3*a* in Table VIII.

We may note also that experiment 6, recorded in Table VII., affords another but more definite illustration of that phase of nitrification, which had apparently been set up in solution 1/4 of Series III., and which, as I stated above, might afford an explanation of the exceptional results afforded by this solution. From the results recorded of this experiment 6, we see that an oxidation of ammonia and possibly also of nitrous acid, took place, and that at the same time small quantities of carbon dioxide, and also of ammonia, or of nitrous acid, or both, were fixed, no doubt, from Winogradsky's experiments, to form organic matter. It is interesting to observe that in each experiment here quoted, the quantity of nitric acid formed is practically exactly equivalent to that of ammonia lost, and that the difference between total inorganic nitrogen before and after fermentation corresponds with the loss of nitrous nitrogen during fermentation. It is just possible from this, that, in nitric fermentation, nitrous acid may enter into the reaction by which organic matters are formed from inorganic materials. But this requires further experimental investigation.

Another point to be noted in reference to these two experiments is, that in one (solution 1/4, Series III.) the volume of dissolved oxygen absorbed is decidedly in excess of that theoretically required for the oxidation of ammonia to nitric acid, while it is a little less in the other experiment (6). This difference may have been due to a difference in character of the organic matter present in the two solutions, since there can be no doubt, from experiments I have yet to describe, that organic matters which have themselves undergone change during a previous first stage fermentation, exercise a marked influence on the subsequent stage of fermentation, or true nitrification, and that these fermented organic matters vary very much in chemical character, so far as nitrification is concerned, I hope to illustrate by further experiments.

The quantities of carbon dioxide and inorganic nitrogen fixed in experiment 6 are small, so small, in fact, that the errors attending their determination are, unfortunately, much too appreciable to warrant an attempt to draw definite conclusions as to any quantitative relationship which may exist between them.

The modification in the method of experimenting employed for the Series IV. renders it possible, it will be seen, to examine the intermediate steps of both the first and the second stage fermentations, and to obtain important results.

To confine attention, in the first instance, to the intermediate steps of the first-stage fermentation recorded in experiments 1, 2, 3, and 4, in Table VII., we notice that during the steps represented by the first three experiments much larger volumes of carbon dioxide were formed than could be accounted for on the assumption that the fermentation in each case consisted of a simple oxidation effected through the agency of the active organisms present in the solution, upon a quantity of the organic matters equivalent to the volume of dissolved oxygen absorbed. Thus, the calculated ratio of carbon dioxide formed to that of the oxygen absorbed by the complete oxidation of the asparagine to carbon dioxide, water, and ammonia, and of potassium sodium tartrate, to its ultimate products of oxidation, are, respectively, as 1·33 : 1, and 1·6 : 1, and if equivalent proportions of these two substances be oxidized at the same time, then the ratio becomes 1·465 : 1. On the other hand the ratios of the volumes of carbon dioxide actually formed to those of oxygen absorbed, in experiments 1, 2, and 3, are as 2 : 1, 1·85 : 1, and 1·86 : 1, respectively. While for experiment 4 this ratio drops nearly to 1 : 1.

It is quite evident, therefore, that, notwithstanding the fact that the earlier steps of the first-stage fermentation represented by experiments 1, 2, and 3, were attended throughout with aërobic conditions, changes other than those which would result from simple oxidation by the dissolved oxygen absorbed must have been set up in the organic matters present in the solution. These changes seem to have been complete by the end of the step represented by experiment 3, for the ratio of carbon dioxide formed to oxygen absorbed during the next stage, represented by experiment 4, drops suddenly to 1 : 1.

This ratio is so low that we are justified in believing that the organic matters which underwent fermentation during this last step were not unfermented portions of the matters originally present, but were themselves the products of the changes which we have seen must have been set up during the earlier steps of fermentation represented by experiments 1, 2, and 3.

In experiment 5 it appears we have illustrated the completion of the first-stage fermentation, and the commencement of the second stage. Judging from the quantities of carbon dioxide, ammonia, and nitrous acid formed, and oxygen absorbed it is probable that nearly the whole of the first-named product should be referred to the first stage. Thus the volume of oxygen theoretically required to oxidize 0·0015 grammes nitrogen as ammonia to nitrous acid equals 3·585 c.cs. Deducting this from the volume of oxygen shown by the experiment to have been absorbed, we get 3·455 c.cs., while the volume of carbon dioxide formed was 3·8 c.cs. These volumes approach sufficiently near in proportion to those which are recorded for the preceding experiment 4, to allow us, I think, to regard them as indicating the volume of oxygen absorbed, and of carbon dioxide formed during the conclusion of the first-stage fermentation, without introducing serious errors.

If this assumption be allowed, we can sum together the volumes of carbon dioxide formed, and of oxygen absorbed, during each of the steps of the first-stage fermentation represented by experiments 1, 2, 3, 4, and 5, and obtain the total volume of carbon dioxide formed, and of oxygen absorbed, by the complete first-stage fermentation of the two organic substances originally present in solution A. Thus:—

—	CO_2	O_2
Experiment 1	15·52	7·81
,, 2	13·53	7·31
,, 3 (× 2),	22·98	12·34
,, 4 (× 2)	15·38	15·12
,, 5 (× 2)	7·6	6·91
Totals	75·01	49·49

The total volumes of carbon dioxide formed, and of oxygen absorbed, at the conclusion of the first-stage fermentation, we then see are 75·01 and 49·49 c.cs., respectively. The ratio of these numbers to one another is as 1·52 : 1, which approximates to the volumes of carbon dioxide and oxygen, which, as I stated above, would be respectively formed and absorbed, were the two substances present in solution A directly oxidized completely to the ultimate inorganic products, carbon dioxide, water, and ammonia, viz. 1.465 : 1.

It appears then, from this, that notwithstanding the fermentative changes which were set up in solution A other than those which would result from simple oxidation during the earlier steps of the first-stage fermentation, the total volume of carbon dioxide formed, and of oxygen absorbed, resulting from the complete first-stage fermentation of the two substances present in the solution, bear approximately the same proportion to one another as if the fermentation had consisted throughout of a simple and direct oxidation by the oxygen absorbed acting upon an equivalent quantity of the mixture of the two substances originally present in the solution.

On turning to the results of the experiments with the dilute solutions of A recorded in Table VIII., we observe that dilution seems to exert a very decided influence on the course, more especially of the earlier steps of the first fermentation

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Thus, from the first experiment with solution A diluted to 1 in 10, it is probable from the quantities of carbon dioxide and ammonia formed, that the first stage had run through but little more than half its course, but notwithstanding this, the ratio of carbon dioxide formed to oxygen absorbed is as 1·4 : 1.

The influence of dilution is still more markedly shown by the results recorded from experiment 3*a* with solution A diluted to 1 in 20. This experiment had been allowed a decidedly longer time for fermentation; and it seems probable from the quantity of ammonia formed, that the first stage had nearly run its complete course.

The ratio between the above two gases, respectively, formed and absorbed becomes as 1·15 : 1.

It seems then from these two experiments that in the fermentative changes that were set up in the earlier steps of the first-stage fermentation of these dilute solutions, the dissolved oxygen took part to a degree increasing with the dilution, and that the resulting compounds were in all probability more highly oxidized than those formed during similar stages of fermentation in the undiluted solution A.

On examining the results of the further experiment (4*a*) with the more dilute solution, recorded in Table VIII., we find evidence to show that the organic matters which are formed during the first stage in so dilute a solution, may themselves undergo further change during nitrification, and give rise to the formation of carbon dioxide coincidentally with the oxidation of ammonia.

But it is of importance to note that from the quantity of nitrous and nitric acids formed and of oxygen absorbed, in experiment 4*a*, the formation of this carbon dioxide could not, have been attended with the absorption of any but a relatively extremely small volume of oxygen.

On turning to the results obtained from the second experiment (2*a*), with the less dilute solution, we find evidence of a similar nature recorded.

It may be urged, and rightly so, that from the way in which the second experiment (4*a*) with the more dilute solution of A was carried out, the volume of oxygen absorbed during fermentation, recorded in Table VIII., is probably too low.

Unfortunately the quantity of liquid left from the experiment 3*a* was not sufficient to allow of re-aëration and analysis in the usual way before rebottling; hence, the necessity of carrying out experiment 4*a* in the manner described in the Table. During the operation of transferring the liquid to a smaller bottle, it, no doubt, absorbed a small quantity of oxygen from the air. This would not, of course, be accounted for by the results recorded in the Table, and therefore the objection that the volume of oxygen given as absorbed during fermentation is probably too low.

I feel confident, however, from experiments which have, from time to time, been made in the course of my work, and which have given me the means of estimating the error attending the operation here described, with a liquid containing so much dissolved oxygen as this one did at the time of re-bottling, that the error certainly does not exceed 0·5 c.c.

It has already been pointed out, when discussing the results of the experiments with the filtered sewage-water, recorded in Table V., that the second-stage fermentation was accompanied by the formation of a decided quantity of carbon dioxide. It therefore appears from this that filtration affects the earlier steps of the first stage in much the same way that dilution does.

It is of importance to note in relation to the objects which I have had in view in the carrying out of this investigation, that, notwithstanding the variations in the chemical changes which these experiments with the solution of asparagine and tartrate have shown to be possible during the intermediate steps of fermentation, according as the quantities of fermentable organic matters and of atmospheric oxygen are varied, relatively to one another, the total quantities of carbon dioxide formed, and of oxygen absorbed, during the whole course of fermentation may, for practical purposes, be taken as independent of such variations, provided that aërobic conditions be maintained throughout the complete course of fermentation.

This will be readily seen when the products of the complete fermentation in each dilute solution are multiplied so as to render them comparable with those obtained from the undiluted solution A, thus:—

Solution.	Experiment.	CO_2	O_2=to N_2O_3	O_2=to N_2O_5	O_2 absorbed.
A/10	1*a* (× 10) - - -	46·7	0·0	0·0	33·4
,,	2*a* (× 10) - - -	30·3	0·0	44·66	51·9
	Totals - - -	77·0	0·0	44·66	85·3
A/20	3*a* (× 20) - -	51·4	0·0	0·0	44·6
,,	4*a* (× 20) - -	23·6	22·94	20·42	32·6
	Totals - - -	75·0	22·94	20·42	77·2

We find from the above Table that the total volumes of carbon dioxide evolved during the whole course of fermentation in the dilute solutions, when multiplied so as to render them comparable to the volume of the same gas evolved by the undilute solution A, are practically equal to one another, and also to the volume evolved during fermentation in the undiluted solution. They are respectively equal to 77, 75, and 75 c.cs.

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With reference to the oxygen absorbed during fermentation, it will be seen that, in experiment 2*a*, the second stage was complete; and the total volume of oxygen absorbed during both the two stages, when multiplied by 10 for the purpose already explained, amounts to 85·3 c.cs.

In experiment 4*a* the oxidation of the nitrogen was not quite complete.

If, however, we add to the volume of oxygen given in the above Table, viz., 77·2 c.cs., the volume of oxygen theoretically required to oxidize the nitrous acid formed in this experiment to nitric acid, viz., 7·68 c.cs., we get a total volume 84·88 c.cs., which approximates to that given for the less dilute solution.

The experiments with solution A do not, unfortunately, give the means of estimating the oxygen absorbed during the second-stage fermentation.

The carbon, both in the asparagine and tartrate employed in these experiments, was carefully determined by combustion in the ordinary way before commencing these experiments. The total organic nitrogen in solution A was also determined by Kjeldahl's method.

From these determinations it was found that the organic carbon per litre of solution was as follows:—

$$\left.\begin{array}{l}0{\cdot}066 \text{ grammes asparagine} = 0{\cdot}0225 \text{ grammes carbon,} \\ 0{\cdot}141 \quad \text{“} \quad \text{tartrate} = 0{\cdot}0234 \quad \text{,,} \quad \text{,,}\end{array}\right\} \text{equivalent to } 85{\cdot}37 \text{ c.cs. } CO_2$$

Organic nitrogen = 0·139 ,, per litre of solution.

As already shown, the volume of carbon dioxide formed by the complete fermentation of these quantities of asparagine and tartrate may be taken as equal to 75 c.cs.

This volume approximates sufficiently close to 85·37 c.cs., the volume which would be formed by the complete oxidation of similar quantities of the same substances, to warrant us in regarding it for purposes of water analyses, as a quantitative expression of the amount of substances originally present in the water.

The solutions experimented with contained minute quantities of peaty colouring matters besides the substances added. These matters, however, probably underwent little, if any, change.

I may here note that the volume of carbon dioxide formed by the fermentation of the peaty matters in the tap-water employed for making up the dilutions may be taken as about 1 c.c. per litre (see p. 561).

With reference to the quantities of ammonia, nitrous and nitric acids formed during fermentation, we observe that in experiment 3*a*, the quantity of nitrogen recorded as ammonia is approximately equal to that of the organic nitrogen originally present. The same may be said of the nitric nitrogen recorded in experiment 2*a*, and of the nitrous and nitric nitrogen recorded in experiment 4*a*. The ammonia determinations recorded in experiments 1 and 2 in Table VIII. are unreliable. They are probably much too high owing to the possibility, which was unfortunately recognised too late, that although the asparagine itself suffered no appreciable decomposition when the original solution A was distilled in the presence of borax, the compounds formed from it by partial fermentation would, and thus give rise to an evolution of ammonia which did not exist as such in the original solution.

To avoid this possible source of error as much as possible, it was determined to nesslerize small portions of the solutions diluted with as large volumes of pure water as possible. The ammonia determinations recorded for all experiments after No. 2, both as regards the solution A itself, and with the diluted solutions made from it, were obtained by this means.

On summing up the results obtained from this series of experiments, we find they afford additional evidence in support of the conclusions which it was possible to draw from those afforded by the three preceding series of experiments with sewage waters, viz., that, when the dissolved oxygen is in excess relatively to the fermentable matter present in a water, the quantities of carbon dioxide and nitric acid formed, and of oxygen absorbed, *after complete fermentation*, may be taken as directly proportional to the quantities of the fermentable matters originally present in the water.

We have also evidence in these results which goes to show that the quantities of carbon dioxide and nitric acid formed on complete fermentation may be taken, for the purpose of water analysis, as quantitative expressions of the fermentable organic carbon, and of the total organic and inorganic nitrogen originally present in the water. This last conclusion is also supported by all the preceding series of experiments.

We see, however, from the results obtained from these solutions of known strength and composition, that the conditions of experimenting must be strictly laid down, and adhered to if definite conclusions are to be drawn, because:—

1. We learn that the volume of carbon dioxide evolved during a first-stage fermentation, relatively to a given volume of oxygen absorbed, may vary, even under continued aërobic conditions, with the relative quantities of fermentable organic matters, and the dissolved oxygen originally present in the water.

When the first stage of fermentation is carried on under conditions such as obtained in the experiments with solution A, viz., the presence of a considerable excess of fermentable organic matters, relatively to the oxygen present, during the earlier steps of the fermentation, we find that the organic carbon present in the solution may be almost completely oxidized to carbon dioxide during the said first-stage fermentation, and that little or none of this gas is formed during the after-fermentation of the ammonia in the same solution.

When, on the other hand, the conditions at the commencement are reversed, viz., the oxygen is large relatively to the fermentable matters present, we see from the experiments with the dilutions of solution A, and from those with the filtered sewage-water used in Series III., that the oxidation of the organic carbon to carbon dioxide during the first stage may be far from complete before the commencement of the second stage of fermentation, but that the organic matters undergo, partially at least, an intermediate stage of oxidation, and that the oxidized matters which result suffer further change during nitrification, and give rise to the formation of decided volumes of carbon dioxide.

2. We also learn that, under the same conditions, not clearly defined by the experiments in question (solution 1/4, Series III., and exp. 6, Series IV.), carbon dioxide and ammonia, and possibly also nitrous acid, may become fixed, even in the presence of organic matters (fermented) presumably to form organic matter.

At the same time we are warranted in believing, from the results hitherto considered, that when a number of dilutions of a water under examination are experimented with, as was done with the samples of sewage-waters above examined, a series of results are obtained which reveal at once an exceptional course of fermentation, such as that shown by solution 1/4 in Series III., and from which definite and valuable conclusions may be drawn as to the character of the organic matters present.

The experiments I have next to quote were made with a view more particularly of gaining further evidence in addition to that already given, as to the relationship between the quantity of inorganic nitrogen formed by the fermentation of sewage-waters under continued aërobic conditions, and that of the total organic nitrogen originally present. These experiments were made with three samples of partially-purified sewage, from the same sewage-works. Each sample was filtered to separate matters in suspension, and diluted with tap-water in the proportion of 1 to 49 respectively. The dilutions were marked for reference, S_1, S_2, and S_3.

The total organic and ammoniacal nitrogen in each dilution was determined at the time of bottling, by Kjeldahl's method, and the ammoniacal nitrogen by direct nesslerization.

The following results were recorded :—

S_1 - - - Organic nitrogen per 1,000 c.cs. of solution = 0·0016 grammes.
S_2 - - - ,, ,, ,, ,, ,, = 0·0020 ,,
S_3 - - - ,, ,, ,, ,, ,, = 0·0006 ,,

The particulars of the experiments are recorded in the subjoined Table :—

TABLE IX.

Solution.	Date.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as NO_5
S_1 - -	Nov. 16, 1894 -	5·89	6·77	16·64	0·0012	0·0	0·0002
,, - -	Jan. 16, 1895 -	10·48	3·62	15·50	0·0023	trace.	0·0002
	Differences -	+4·59	−3·15	−1·14	+0·0011	—	0·0
S_2 -	Nov. 16, 1894 -	7·85	7·35	16·10	0·0036	0·0	0·0002
,, - -	Jan. 21, 1895 -	15·18	0·15	15·16	0·0046	0·00112	0·0004
	Differences -	+7·33	−7·23	−0·94	+0 001	+0·00112	+0 0002
S_3 - -	Nov. 17, 1894 -	7·13	7·44	16·06	0·001	0·0	0·0004
,, - -	Jan. 24, 1895 -	8·63	2·46	15·18	0·0001	0·0	0·0018
	Differences -	+1·50	−4·98	−0·88	−0·0009	—	+0·0014
Tap-water	Nov. 17, 1894 -	5·01	7·80	15·96	0·0	0·0	0·0002
,, I.	Jan. 23, 1895 -	5·11	7·72	16·01	0·0	0·0	0·0002
,, II.	March 4, 1895 -	5·20	7·60	16·03	0 0	0·0	00·002

So far as the relationships between the quantity of organic nitrogen originally present in a water, and that of the inorganic nitrogen which finally results from its complete fermentation are concerned, the above results do not do more than afford additional evidence of the general conclusions which those of the preceding experiments have yielded, viz., that much of the greater portion of the fermentable organic nitrogen in a water, is converted into inorganic nitrogenous bodies. It is impossible, it is to be feared, to obtain more accurate results, with the present known method for the nitrogen determinations, whereby any more definite inference as to this relationship can be drawn than the general one just given, since the errors attending the various determinations required become very much too appreciable.

Notwithstanding, however, this want of precision in the nitrogen determination, the experimental details, quoted in the above Table IX., when considered together afford most valuable information as to the character and quantity of fermentable matters present originally in the respective solutions experimented with.

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Thus, for each solution we have a loss of oxygen determined with great accuracy. That recorded for the solution S_3 gives the volume of this gas required for complete fermentation, while the loss recorded for each of the other two solutions is seen to cover only a partial fermentation of the matters present. The volume of oxygen required for the complete fermentation of these two solutions could have been determined by additional experiments; and with the data which would have been thus obtained, we could have contrasted the three solutions as to the total volume of oxygen required for complete fermentation, or, what is of much greater importance, as we have seen already, in the analysis of water polluted with such matters as sewage, we could have distinguished the volumes of oxygen required for each of the two stages of fermentation in each.

Fixation of Atmospheric Nitrogen.

There are other results which these experimental solutions have furnished, to which the greatest interest will be attached, viz., those afforded by the atmospheric nitrogen determinations. These show that very distinct quantities of that gas were absorbed during fermentation in each solution, and they are, so far as I know, the first recorded observations showing directly that atmospheric nitrogen may be absorbed during bacterial fermentation.*

On reference to the Table IX. it will be seen that the loss of nitrogen was 1·14, 0·94, and 0·88 c.cs., for the three solutions respectively. These numbers are much too high to ascribe to experimental errors, and in proof of this I have appended to the results obtained with the experimental solutions those afforded by samples of the tap-water employed for making the dilutions, which were bottled and kept under exactly similar conditions.

In reference to these experiments with the tap-water, I may note that they afford additional evidence to that already given, that the minute quantity of peaty matters contained therein really undergo slow fermentation to a degree, which begins to be indicated by the method of observation which I have employed in these experiments, after about four months' keeping.

Fixation of Carbon Dioxide and of Ammoniacal Nitrogen.

There is yet one further point of interest which I have to mention in reference to these solutions, namely, an additional experiment which I made with the portion of the solution S_2, which remained after the various analyses had been made on the day recorded, viz., January 21st. It will be seen on reference to Table IX. that the solution on that date was very similar in composition, so far as the probable character of the organic matters, and also so far as the composition of the inorganic nitrogenous bodies it contained, was concerned; to those in which we have already observed a fixation of carbon dioxide and inorganic nitrogen to have occurred during fermentation, viz., in solution 1/4 and in experiment 6, recorded in Tables V. and VII. respectively. In order to ascertain whether a similar action would take place during a further fermentation of solution S_2, the remainder mentioned above was re-aerated and bottled, and analysed before and after keeping, with the following results:—

Date.	CO_2.	O_2.	N_2.	N as NH_3.	N as N_2O_3.	N as N_2O_5.
January 25, 1895 - -	10·67	7·6	15·22	0·0045	0·00128	0·0006
March 1, 1895 - - -	9·90	0·0	15·25	0·0027	0·00128	0·00182
Differences - -	–0·76	–7·7	—	–0·0018	—	+0·00122

From the results just given, it will be seen that a fixation of carbon dioxide and ammoniacal nitrogen really occurred, as was anticipated, during further fermentation, but that apparently the nitrous nitrogen, unlike that in the case of the two solutions above referred to, did not take part.

Before passing on to describe my experiments with waters containing considerable quantities of peaty matter, I will give some further experimental results, which will be found to support the general conclusions which have been drawn from those already considered.

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* Since the above was written, M. Winogradsky has published a paper describing the isolation and properties of a butyric ferment, which has the power of fixing free nitrogen.—Arch. Sciences Biol. 1895, 3, 297–352; also Chem. Soc. Jour. Abstr. 68, 283.

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The full details of the experiments are recorded in the subjoined Tables:—

SERIES V.—COMMENCED 27TH JUNE, 1894.

TABLE X.—*Experiments with diluted Sewage-Water.*

No. of Experiment.	Date of Commencement, and of conclusion of Experiment.	Nature of Experiment.	CO_2	O_2	N.	N as NH_3	N as N_2O_3.	N as N_2O_5.	REMARKS.
1	June 27, 1894	1 volume of sewage water, diluted with 2 volumes of distilled water, and aerated	76·80	4·50	13·85	0·02	0·0	0·0	Odour slightly offensive.
	Aug. 30, „	Same, after fermentation	104·96	0·00	13·68	0·022	0·0	0·0	Very offensive odour of putrefaction and SH_2.
		Differences ...	+28·16	−4·50	...	+0·002	...	...	
2	Aug. 30, „	1 volume of remainder of preceding solution, after fermentation, diluted with 2 volumes of distilled water, and aerated	33·79	5·37	14·42	0·008	0·0	0·0	Distinct odour of SH_2.
	Nov. 21, „	Same, after fermentation	38·62	0·0	14·22	0·012	0·0	0·0	Offensive odour of putrefaction and SH_2.
		Differences ...	+4·83	*−5·37	...	+0·004	...	...	
3	Nov. 21, „	Remainder of preceding solution, diluted with three times its volume of distilled water	8·94	7·39	15·17	0·003	0·0	0·0	
	Jan. 12, 1895	Same, after fermentation	9·54	1·34	15·02	0·0	0·0	0·0015	Quite free from odour.
		Differences ...	+0·60	−6·05	...	−0·003	...	+0·0015	

SERIES VI.—COMMENCED 30TH DECEMBER, 1892.

TABLE XI.—*Experiments with Potassium Sodium Tartrate.*

Solution IV. contained 0·1 grammes carbon as potassium sodium tartrate (cryst). } per litre.
0·1 „ sodium carbonate,
0·1 „ potassium phosphate,

Date of conclusion of Experiment.	Solution.	CO_2 I.	CO_2 II.	O_2 I.	O_2 II.	N_2 I.	N_2 II.	N as NH_3 I.	N as NH_3 II.	N as N_2O_5 I.	N as N_2O_5 II.
Aug. 10, 1893	IV.	22·42	40·84	8·40	0·00	16·72	16·87	0·0	0·0001	0·0001	0·00
	Differences -	+18·42		−8·40		...	...	+0·0001		−0·0001	
April 4, 1894	IV./5	7·49	32·55	8·40	0·00	16·72	16·47	0·0	0·0005	0·0001	0·00
	Differences -	+25·06		−8·40		...	...	+0·0005		−0·0001	
April 4, „	IV./10	5·62	23·17	8·40	0·00	16·72	16·48	0·0	0·0004	0·0001	0·00
	Differences -	+17·55		−8·40		...	...	+0·0004		−0·0001	
Dec. 21, „	IV./40	4·23	9·45	8·40	1·94	16·72	16·25	0·0	0·0	0·0001	0·0006
	Differences -	+5·23		−6·46		...	...			+0·0005	
Dec. 21, „	IV./80	3·99	7·84	8·40	5·49	16·72	16·47	0·0	0·0	0·0001	0·0006
	Differences -	+3·85		−2·91		...	...	...	...	+0·0005	

REMARKS.—The ammonia formed during fermentation in dilutions IV./5 and IV./10 was derived, no doubt, from the nitrate, and possibly also, in the case of the latter dilution, from the peat in the tap-water.

Owing to the length of time (just two years) the dilutions IV./40 and IV./80 were kept, there can be little doubt, since an excess of oxygen was present in each, that the peaty matter in the tap-water employed for their preparation underwent fermentation as well as the tartrate. This will account for the nitrates formed in these solutions, and also for the relatively large volumes of carbon dioxide found therein, compared with the less dilute relations. (See Table XIV.)

The considerable differences shown by the atmospheric nitrogen determinations in the case of the dilute solutions, may be, partially at least, due to fixation, but this may also be due to greater errors than those commonly arising, owing to the very long time the solutions were kept.

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* This volume of oxygen was probably not all consumed by the fermentative process. SH_2 and other reduced products of putrefactive fermentation were present at the commencement of the experiment, and a portion of the oxygen was, no doubt, taken up by the direct oxidation thereof.

SERIES VII.—COMMENCED 30TH DECEMBER, 1892.

TABLE XII.—*Experiments with Potassium Sodium, Tartrate, and Ammonium Chloride.*

Solution B containing 0·0468 grammes carbon as potassium tartrate (cryst.),
0·01 ,, nitrogen as ammonium chloride,
0·10 ,, sodium carbonate,
0·10 ,, potassium phosphate,
} per litre.

Date of conclusion of Experiment.	Solution.	CO		O₂		N₂		N as NH₃		N as N₂O₅		N as N₂O₃	
		I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
1893													
May 5	B	21·45	44·16	8·45	0·0	16·81	16·68	0·01	0·0095	0·0001	0·00	0·00	0·00
	Differences	+22·71		− 8·45		...	...	...	...	...	...	...	...
,, 8	B/5	7·30	21·99	8·46	0·0	16·81	16·78	0·002	0·001	0·0001	0·00	0·00	0·00
	Differences	+14·69		− 8·46		...	...	− 0·001		−0·0001		...	...
,, 10	B/10	5·53	13·59	8·46	0·07	16·81	16·62	0·001	0·00005	0·0001	0·0004	0·00	0·0006
	Differences	+ 8·06		− 7·76		...	...	− 0·00095		+0·0003		+0·0006	
,, 10	B/15	4·94	10·49	8·46	3·39	16·81	16·63	0·00067	0·00	0·0001	0·00047	0·00	0·00048
	Differences	+ 5·55		− 5·07		...	...	− 0·00067		+0·00037		+0·00048	
,, 15	B/20	4·64	8·63	8·46	4·35	16·81	16·62	0·0005	0·00	0·0001	0·0008	0·00	trace
	Differences	+ 3·99		− 4·11		...	...	− 0·0005		+0·0007		+trace	
,, 16	B/40	4·20	6·23	8·46	6·16	16·81	16·60	0·00025	0·00	0·0001	0·0005	0·00	0·00
	Differences	+ 2·03		− 2·10		...	...	− 0·00025		+0·00045		...	...

REMARKS.—It will be observed that solution B contained practically a similar quantity of organic carbon to solution A (Table VII.), and on comparing the volumes of carbon dioxide formed on complete fermentation of the tartrate in these solutions with those obtained from the tartrate and asparagine in solution A and its dilutions, they will be found approximately equal thereto. (See also p. 613, and Table XVII.)

SERIES VIII.—COMMENCED 27TH MARCH, 1893.

TABLE XIII.—*Experiments with White of Egg.*

Solution I. contained 0·15 grammes white of egg,
0·10 ,, potassium phosphate,
0·10 ,, sodium carbonate,
} per litre.

Date of conclusion of Experiment.	Solution.	CO₂		O₂		N₂		N as NH₃		N as N₂O₃		N as N₂O₅	
		I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
1894													
March 29	I.*	22·70	39·24**	7·80	0·00	15·68	15·64	0·00	0·0026	0·00	0·00	0·0001	0·00
	Differences	+16·54		− 7·80		...	...	+0·0026		0.00		− 0·0001	
,, 30	I./5†	7·77	13·18	7·80	1·43	15·68	15·47	0·00	0·00	0·00	0·00	0·0001	0·0017
	Differences	+ 5·41		− 6·37		...	...	0·00		0·00		+0·0016	
,, 30	I./10†	5·91	9·42	7·80	3·93	15·68	15·55	0·00	0·00	0·00	0·00	0·0001	0·0012
	Differences	+ 3·51		− 3·87		...	...	0·00		0·00		+0·0011	
,, 30	I./20†	4·97	6·95	7·80	5·23	15·68	15·52	0·00	0·00	0·00	0·00	0·0001	0 001
	Differences	+ 1·98		− 2·57		...	...	0·00		0·00		+0·0009	
May 2	Tap-water I.	4·04	4·94	7·80	6·63	15·60	15·50	0·00	0·00	0·00	0·00	0·0001	0·0008
	Differences	+ 0·90		− 1·07		...	....	0·00		0·00		+0·0007	
,, 3	Tap-water II.	4·04	4·89	7·80	6·78	15·60	15·50	0·00	0·00	0·00	0·00	0·0001	0·0008
	Differences	+ 0·85		− 1·02		...	...	0·00		0·00		+0·0007	

* Very offensive. † Quite free from odour.

** The remainder of this solution, immediately after analysis, was mixed with an equal bulk of distilled water. The mixture, after thorough aeration and analysis, was then put into the same bottle as that in which solution I. was kept and preserved in the usual way. After a lengthened period it was again examined, with the following results :—

1895													
January 2		20·55	23·09	7·30	0·73	15·60	15·84	0·0014	0·00	0·00	0·00032	0·00	0·0010
	Differences‡	+2·54		− 6·84		...	...	− 0·0014		+0·00032		+0·0010	

‡ After the conclusion of this experiment, a considerable quantity of a very thin transparent scale-like deposit was noticed on the sides of the bottle. See also notes to Table XI.

PART II.—EXPERIMENTS WITH DIFFICULTLY FERMENTABLE MATTERS.

Colouring Matters of Peat.

As an example of difficultly fermentable organic matters, I have employed an extract of fresh peat, collected from a bog which was slightly submerged under running water, and which was situated on one of the Wicklow mountains, and far removed from any source of contamination with animal matters.

The sample of peat was collected on September 15th, 1893.

Two days after, an extract was prepared from it by boiling it in tap-water containing a little sodium hydrate. The extract was filtered into a large glass-stoppered jar, which it filled to about two-thirds of its capacity. The extract was then of a deep brown, and it was allowed to ferment until March 8th in the following year, the stopper of the jar being taken off from time to time to renew the air. It was then thoroughly mixed with about five times its bulk of tap-water, and allowed to settle till the following day, when about six litres were decanted off, and the different experiments commenced, which are recorded in Tables XIV. and XV.

The results of these experiments were looked forward to with very much interest for several reasons :—

First, it was known that peaty colouring matters in river-waters suffered but little oxidation or other change, unless the waters were subjected to the action of such bodies as clay, when the peaty matters were more or less completely separated by the precipitating action of the clay. There was good reason to believe, however, that the peaty matters in water, when fresh, do undergo at least a slight chemical change. This was evident from the analyses published in the "Sixth Report of the Rivers Pollution Commissioners."*

These show that the proportion of carbon to nitrogen in unoxidized peaty matter contained in upland surface water is as 11·9 : 1 ; but in peaty matter which has been exposed to oxidation in lakes or large reservoirs, the proportion became 5·9 : 1.

It was quite an open question, however, whether these matters undergo fermentation when present alone, or whether they exert any influence on the fermentation of fermentable matters when present together with such in a water.

Again, it will be observed that the proportion of carbon to nitrogen in peaty matters is very similar to that of the carbon and nitrogen found in the fermented matters which result from the complete fermentation of sewage during slow filtration through sand. We find from an experiment recorded by Dr. Frankland (Frankland's 'Experimental Researches," p. 751) that this proportion may be from 9·6 : 1 to 6·3 : 1.

The fermented organic matters which are formed during slow filtration of sewage through such substances as sand or pumice, besides showing a similarly high proportion of carbon to nitrogen, as peaty matter, and we may take it, a similar resistance to fermentation, since it must be remembered these matters are obtained in very decided quantities even after a fermentation in a filter, which has been so complete, that little more than traces of the original ammonia in the sewage may be left unfermented, also possess other properties such as colour and optical properties, which are very similar to those of peaty-colouring matters. Thus, on allowing sewage to percolate very slowly through a pumice filter, I have obtained effluent waters therefrom, coloured very decidedly with a brown tint, which could not be distinguished from the brown varieties of peaty matter, and which on analysis gave the proportion of carbon to nitrogen as 7·1 : 1.

Neither could it be distinguished from peaty water coloured to a similar depth of tint when examined by Professor W. N. Hartley's spectroscopic method. A similar series of dilutions of both afforded identical ultra violet absorption spectra.

The experiments with easily fermentable matters, which have already been quoted, more especially those with the effluent water from the sand filtration recorded in Table V., afford abundant evidence that the organic matters which are formed during the first-stage fermentation of animal and vegetable substances may themselves take part in, and suffer a further oxidation during the subsequent second stage.

The question naturally suggested itself—Do peaty matters undergo similar fermentative changes under similar conditions ?

This question appeared the more interesting because from those of my experiments already recorded, and from others, I had come to the conclusion that the presence of small quantities of fermented organic matters, such as peaty-colouring matters, probably are essential to the *nitric* fermentation of *ammonia*, and that the failure to obtain a nitric fermentation of this body under conditions which, as the researches of Professor P. F. Frankland and Mrs. G. C. Frankland, of Warrington, and of Winogradsky, have abundantly demonstrated, are most favourable to nitrous fermentation, may be ascribed to the complete absence of peaty or humus-like bodies.

In every experiment which I have made, and in which it has been found that the oxidation of ammonia to nitric acid has been complete, small quantities of peaty or fermented organic matters have always been present. The same may be said, I think, of the experiments of the above observers in which nitric acid was formed.

In other experiments which I shall have to describe, and in which the only change in the conditions has been a practical absence of all organic matters, I have also obtained abundant nitrous fermentation, but no nitric. In reference to the experiments last mentioned, it is of importance and of interest to note that the organisms present were of the same mixed character as in the case of those experiments in which, as stated, I obtained nitric fermentation.

With these prefatory remarks, I may now proceed to the discussion of the experiments with the extract of peat above mentioned.

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* See also Dr. P. Frankland's Article on Water in "Thorpe's Dictionary of Applied Chemistry," vol. iii., p. 965.

The details and results are recorded in the two following Tables :—

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SERIES IX.—COMMENCED 9TH MARCH, 1894.

TABLE XIV.—*Experiments with a Solution of Peat.*

Solution P contained 0·0033 grammes nitrogen as ammonia
0·1336 ,, organic carbon
0·0079 ,, organic nitrogen
per litre

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O
1	1894. March 9	Solution P	114·65	7·14	14·27	0·0033	0·0	0·0
	May 11	Same after fermentation*	136·03	0·0	14·70	0·0044	0·0	0·0
		Differences	+21·38	−7·14	—	+0 0011	—	—
2	,, 18	Remainder of preceding solution diluted with twice its bulk of distilled water aerated and exposed to the air for a week, then aerated again and bottled = P/3†	41·46	7·44	14·96	0·0012	0·0	0·0
	July 27	P/3 after fermentation	48·96	0·0	15·08	0·00048	0·0	0·0004
		Differences	+7·50	−7·44	—	−0·00072	—	0·0004
3	July 27	Remainder of preceding solution aerated	44·91	6·45	12·86	0·00046	0·0	0·0004
	Nov. 15	Same after fermentation	49·24	0·0	13·09	0·00014	0·0	0 0002
		Differences	+4·33	−6·45	—	−0·00032	—	−0·0002
4	Nov. 16	Remainder of preceding solution aerated	48·06	7·24	14·86	0·00014	0·0	0·0002
	1895 Jan. 29	Same after fermentation	50·96	2·75	14·67	0·0	0·0	0·0003
		Differences	+2·90	−4·49	—	−0·00014	—	+0·0001
5	1894 May 18	A portion of the solution P/3 from experiment No. 2, diluted with twice its bulk of distilled water =P/9	14·70	7·46	14·77	0·0004	0·0	0·0
	June 12	Same after fermentation - I.	16·67	3 95	14·67	0·0	0·0	0·00035
	July 20	Another bottle of same after fermentation, - II.	19·02	1·77	14·74	trace	0·0	0·00035
	July 23	Another bottle - III.	19·21	1·66	14·69	0·0	0·0	0·00035
		Differences - I.	+1·97	−3·51	—	−0·0004	—	+0·00035
		,, - II.	+4·32	−5·69	—	−0·0004	—	+0·00035
		,, - III.	+4·51	−5·80	—	−0·0004	—	+0·00035
6	July 21	Remainder of solution II. aerated	17 75	6·42	13·22	trace	0·0	0·00035
	Nov. 22	Same after fermentation - IV.	19·15	3·91	13·27	0 0	0·0	0·0007
		Differences - IV.	+1·40	−2·51	—	—	—	+0·00035
	1895 Jan. 30	Another bottle of same after fermentation - V.	19·25	3·89	13·11	0·0	0·0	0·0007
		Differences - V.	+1·50	−2.53	—	0·0	0·0	+0·00035

* Very offensive odour. † Free from offensive odour.

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Series X.—Commenced 9th March, 1894.

Table XV.—*Experiments with Solution of Peat and Ammonium Chloride.*

Solution PA (= P/2 + AmCl.) contained	0·1	grammes	ammonium chloride	per litre.
	0·069	„	organic carbon	
	0·004	„	organic nitrogen	

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
1	1894. March 9	Solution PA = P/2 + Am Cl.	59·29	7·4	15·14	0·1	0·0	0·0001
	May 12	Same after fermentation	72·26	0·0	15·17	0·1	0·0	0·0
		Differences	+12·97	−7·4	—	—	—	−0·0001
2	May 14	Remainder of PA after fermentation diluted with twice its bulk of distilled water and aerated = PA/3	23·80	7·26	14·54	0·032	0·0	0·0
	June 15	Same after fermentation	25·55	0·0	14·55	0·028	0·00225	0·0
		Differences	+2·75	−7·26	—	−0·004	+0·00225	—
3	June 18	Remainder of PA/3 after fermentation aerated	22·74	6·8	13·58	0·027	0·0024	0·0004
	June 28	Same after fermentation	22·18	0·0	13·60	0·023	0·0024	0·0037
		Differences	−0·56	−6·8	—	−0·004	—	+0·0033
4	June 28	Remainder from preceding aerated	15·51	6·5	12·99	0·002	0·0021	0·004
	July 17	Same after fermentation	16·58	0·15	13·09	0·0198	0·00048	0·0065
		Differences	+1·07	−6·35	—	−0·0022	−0·0016	+0·0025
5	July 21	Remainder from preceding aerated	5·82*	6·55	13·19	0·019	0·0006	0·0070
	1895. Jan. 28	Same after fermentation	6·58	0·0	13·29	0·018	0·0032	0·0088
		Differences	+0·77	−6·55	—	−0·001	+0·0026	+0·0018
1*a*	1894. March 9	Solution PA diluted with tap-water in the proportion of 1 to 9 = PA/10 = P/20 + Am Cl.	9·46	7·5	15·54	0·01	0·0	0·0001
	May 14	Same after fermentation	21·52	0·0	15·55	0·007	0·0033	0·0
		Differences	+12·06	−7·5	—	−0·003	+0·0033	—
2*a*	May 16	Remainder of PA/10 aerated	18·99	7·24	14·58	0·007	0·0033	0·0
	June 21	Same after fermentation	19·96	0·0	14·48	0·0035	0·006	0·0004
		Differences	+0 97	−7·24	—	−0.0035	+0·0027	+0·0004
3*a*	June 22	Remainder from preceding aerated	14·83	7·2	14·15	0·0024	0·0009†	0·0067†
	1895. Jan. 31	Same after fermentation	18·39	0·0	13·96	0·00005	0·004	0·00815
		Differences	+3·56	−7·2	—	−0·00239	+0·0031	+0·00145
1*b*	1894. March 9	Solution PA diluted with tap-water in the proportion of 1 to 19 = PA/20 = P/40 + Am Cl.	6·69	7·5	15·54	0·005	0·0	0·0001
	May 15	Same after fermentation	15·02	0·0	15·55	0·0026	0·0021	0·0004
		Differences	+8·33	−7·5	—	−0·0024	+0·0021	+0·0003
2*b*	May 17	Remainder of PA/20 aerated	11·82	7·2	14·37	0·0018	0·0021	0·0004
	June 20	Same after fermentation	11·06	0·0	14·28	0·0001	0·00018	0·00332
		Differences	−0·76	−7·2	—	−0·0017	−0·00192	+0·00292

Remarks.—*The very rapid reduction of carbonic acid, here shown during the time the liquid was exposed to the air, was confirmed by a duplicate analysis (5·81). The loss may have occurred by diffusion, but I have not observed so great a loss in any other of my experiments under similar conditions.

† These results show that an extremely rapid reduction of nitrous to nitric acid, occurred when the liquid was exposed to the air between the 21st and 22nd June. The figures were confirmed by duplicate analyses.

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Referring to Table XIV. we find, from the first experiment, that the first-stage fermentation of solution P was not complete at the time of commencing the experiments; the remaining portions of solution P were in consequence diluted, as described in the Table, with twice their bulk of distilled water, and exposed to the air for a week to allow of its completion.

From the fact that nitrification had commenced in experiment 2, we may take it that the first-stage fermentation in the solution had been completed. The points most markedly exhibited by experiments 2 and 3 are a formation of carbon dioxide and a loss of oxygen and ammonia. As for the indications of nitrification, they are decided in the former experiment; but the nitric acid formed was equivalent to only about half the quantity of ammonia absorbed, while in the latter experiment no nitric acid appears to have been formed, although a very decided quantity of ammonia was absorbed. It appears then from these experiments that a *fermentation of small quantities of ammonia in the presence of considerable quantities of peaty colouring matters may take place, in such a manner that the ammonia is absorbed, and carbon dioxide is formed, while oxygen is consumed in relatively considerable volumes, but that little or no nitric (no nitrous) acid may be produced.*

In experiment 4 the nitric acid formed is about equivalent to the ammonia absorb ed. It is important, however, to note that this last product is the least marked result of the fermentation; the volume of carbon dioxide formed and oxygen consumed being relatively both very much larger in quantity.

Experiments 5 and 6 were made with a diluted portion of solution P/3 prepared for experiment 2, and the former of these two experiments was commenced on the same day as the last mentioned. It is possible and interesting, therefore, to compare the results obtained with the less and more dilute solutions P/3 and P/9.

The first result of fermentation shown with bottle I, on June 12th, less than a month afterwards, was the complete fixation of the ammonia, and the formation of a quantity of nitric acid practically equivalent to the ammonia lost, accompanied by the formation of carbon dioxide.

The results obtained on keeping the other portions of the same solution (in bottles II. and III.) for a further period of about six weeks, were, a further formation of a decided quantity of carbon dioxide and a consumption of oxygen, *but no additional formation of nitric acid.* On re-aerating however, a portion of the solution in bottle II., remaining from the experiment, and keeping it in two bottles for further periods, one of four, and another of six months, we find a formation of carbon dioxide and a consumption of oxygen, accompanied by a formation of a decided quantity of nitric acid.

The carbon dioxide and nitric acid formed during this last fermentation must have been derived solely from the peaty matters present in the solution. They therefore confirm the evidence which was afforded by the experiment with tap-water recorded in Tables IX. and XIII., to the effect that the minute quantities of peaty matter in the tap-water underwent a fermentation, though an extremely slow one, into carbon dioxide and nitric acid.

The influence of dilution on the fermentation illustrated by these experiments becomes more decidedly apparent when the oxygen consumed, and the products formed, during the different stages of fermentation represented by experiments 2, 3, and 4, with less dilute solutions, and by experiments 5 (bottle III.), and 6 (bottle V.) are respectively added together and compared Thus:—

		O_2	CO_2	N as NH_3	N as N_2O_3
Solution P/3 -	Exp. 2, 3, and 4.	−18·38	+14·73	−0·0012	+0·0003
Solution P/9 -	Exp. 5 (III.) and 6 (V.)	−8·33	+6·01	−0·0004	+0·0007

In the less dilute solution P/3, it becomes evident from the above figures that during fermentation a considerable quantity of ammonia was absorbed, and that the quantity of nitric acid formed was, for the period during which the solution was under examination, only about one-fourth that of the ammonia originally present.

On the other hand, in the more dilute solution the reverse action appears to have taken place, since the quantity of nitric acid formed was nearly double that of the ammonia originally present.

Again, the volume of carbon dioxide formed in proportion to that of the oxygen consumed was larger, relatively, in the less than in the more dilute solution.

The fact that peaty matters, when mixed with ammonium chloride, readily undergo fermentation is more clearly demonstrated by the experiments recorded in the next Table XV.

These experiments, it will be noticed, were made with another portion of the same solution of peat, but with this difference, it was mixed with a relatively larger quantity of ammonium chloride. The results then obtained show that a variety of interchanges may occur between peaty matters and ammonia during fermentation.

Thus from experiment 2 we find 7·26 c.cs. oxygen, and 0·004 grammes of ammoniacal nitrogen were taken up, and only 0·00225 grammes of nitrous nitrogen were formed; the volume of oxygen theoretically equivalent to this quantity of nitrous nitrogen being 5·38 c.cs., a volume much less than that actually consumed. From experiment 3 we find the quantities of oxygen and ammoniacal nitrogen taken up are respectively 6·8 c.cs. and 0·004 grammes, and that of nitric nitrogen formed, 0·0033 grammes; no carbon dioxide was formed during this stage of fermentation, but, on the contrary, 0·56 c.cs. were fixed.

The volume of oxygen theoretically equivalent to the nitric nitrogen formed, viz., 0·0033 grammes, is 10·53 c.cs., a volume this time much in excess of that actually consumed. It would seem from the last observation that an interchange between the peaty matters and ammonia took place during this step of the fermentation, but no doubt of a different character, notwithstanding the fact that *carbon dioxide was fixed* rather than formed. It is perhaps right to mention that all

Dr. Adeney. the determinations given in this Table, and in the preceding one, were made with extreme care, all being checked by duplicate analyses, and in the case of many of the nitrogen determinations by triplicate analyses, and further that some of the nitric nitrogen determinations were confirmed by Crum's method with Lunge's nitrometer.

Experiment 4 demonstrates another phase of interchange between the two bodies, and it must be noted of nitrous acid, during fermentation, thus the quantities of oxygen and ammoniacal and nitrous nitrogen taken up were, respectively, 6·35 c.cs., 0·0022 grammes, and 0·0016 grammes, and of carbon dioxide and nitric nitrogen formed, 1·07 c.c. and 0·0025 grammes. The volume of oxygen theoretically equivalent to this last mentioned quantity of nitric nitrogen, supposing part of it was derived from the 0·0016 grammes of nitrous nitrogen taken up and the rest from ammoniacal nitrogen, is 4·15 c.cs., a volume less again than that consumed.

In the last experiment with PA/3, we find a still further phase of interchange during fermentation demonstrated, the quantities of oxygen and ammoniacal nitrogen shown by this experiment as being taken up, and of nitrous and nitric nitrogen formed being, respectively, 6·55 c.cs., 0·001 grammes, 0·77 c.cs., 0·0026 grammes, and 0·0018 grammes. The total quantity of nitrous and nitric nitrogen formed was thus equal to 0·0044 grammes, a quantity largely in excess of the ammoniacal nitrogen taken up. The total volume of oxygen theoretically equivalent to the nitrous and nitric nitrogen formed, assuming that both were derived from the ammoniacal nitrogen, is 11·96 c.cs. There can, therefore, be little doubt from these results that the nitrous and nitric nitrogen formed during this last step of the fermentation, represented by experiment 5, were derived from compounds resulting from the interchanges which, we have seen, must have occurred between the peaty matters and ammonia present in the water during the earlier steps of the fermentation.

It must be remembered in reference to this point, that the organic nitrogen actually present in combination with the peaty matters in the solution PA/3 at the time these experiments were commenced was only 0·00133 grammes. If we sum together the quantities of ammoniacal nitrogen absorbed, and of the products formed, we see clearly that, although as above shown, the peaty matters played an essential part in the changes which occurred during fermentation, but little carbon dioxide was formed, and that, so far as oxidized products are concerned, the fermentation was practically a nitrogen fermentation. The total figures are :—

O_2	CO_2	N as NH_3	N as N_2O_3	N as N_2O_5
− 26·96 c.cs.	+ 4·59 c.cs.	− 0·0112 grms.	+ 0·00645 grms.	+ 0·0076 grms.

The total nitrogen oxidized was, as will be seen from these figures, 0·01405 grammes, a quantity decidedly in excess of the ammoniacal nitrogen absorbed.

4·59 c.cs. of carbon dioxide is equivalent to 0·0025 grammes carbon, which is but a small fraction of the total quantity of the organic carbon originally present in solution PA/3, viz., 0·023 grammes.

We have seen that the reverse action to this took place in the solution P/3, which contained but little ammonia relatively to peaty matters. Thus the total volume of carbon dioxide formed was equal to 14·73 c.cs. This volume is equivalent to 0·008 grammes carbon. The oxidised nitrogen, it will be remembered, only amounted to 0·0003 grammes.

One further feature in connection with one of these experiments demands some notice. It is the very sudden diminution of carbon dioxide (shown by the first analysis in experiment 5) which occurred while the solution was kept in a stoppered bottle, only partially filled, from the 17th to the 21st July. No suitable explanation has occurred to my mind to account for this loss. No doubt a portion was due to diffusion into the air-space in the bottle, but with the records of the preceding experiments with the same solution before one, it is difficult to conceive that the loss was wholly due to this cause. Another source of loss lies doubtless in the possibility of a portion of the gas being fixed by fermentation.

On turning to the experiments with PA/10, we find the influence of dilution shown as markedly as we have already seen it to be in the case of solution P/3 and of the more dilute solution P/9.

Experiment 1*a* shows that the nitrous nitrogen formed was practically equal to the ammoniacal nitrogen absorbed, but that the fermentative products differ essentially in one particular from those obtained simultaneously with nitrification with the less dilute solution, in that a considerable volume of carbon dioxide was formed. But notwithstanding this, the oxygen theoretically equivalent to the nitrous nitrogen = 7·85 c.cs., is slightly in excess of that consumed.

In experiment 2*a* the nitrous and nitric nitrogen together practically equalled the ammoniacal nitrogen lost, but this time, however, a very small volume of carbon dioxide was formed. The volume of oxygen theoretically equivalent to the nitrous and nitric nitrogen formed is 7·70 c.cs., a volume also slightly in excess of that actually consumed, viz., 7·24 c.cs.

It is interesting to note that the fermentation during these two experiments was practically a nitrous fermentation, but that when the solution remaining after the conclusion of the second experiment was kept in a bottle only partially filled for a single day, the nitrous acid was almost completely fermented to nitric acid.

During fermentation in experiment 3*a*, the nitrous and nitric nitrogen formed, amounting to 0·00355 grammes, was considerably in excess of the ammoniacal nitrogen lost, and a decided quantity, viz., 3·56 c.cs., of carbon dioxide was produced. Nevertheless the oxygen theoretically equivalent to the total nitrous and nitric nitrogen, viz., 8·81 c.cs., is decidedly in excess of that actually consumed, 7·2 c.cs.

On summing together the differences from each experiment, it will be seen that, by the time of the conclusion of the experiment 3*a*, nearly all the fermentable matters, *i.e.*, both peat and ammonia, originally present in solution PA/10, must have been fermented, thus :—

O_2	CO_2	N as NH_3	N as N_2O_3	N as N_2O_5
−21·94 c.cs.	+16 59 c.cs.	−0·00889 grms.	+0·0091 grms.	+0·00185 grms.

16·59 c.cs. CO_2 are equivalent to 0·00896 grammes. The organic carbon originally present in the solution PA/10 was 0·0089 grms. The exact coincidence between these numbers is probably accidental. Again, the total nitrous and nitric nitrogen amounts, it will be observed, to 0·01095, while the total organic and inorganic nitrogen present in the solution when the experiments were commenced was 0·0107 grammes.

The volume of oxygen theoretically equivalent to the nitrous and nitric nitrogen, assuming that both were derived from the ammoniacal nitrogen, is equal to 27·66 c.cs., which is very much larger than that found by analysis to have been consumed. We may draw the conclusion, then, that the oxygen of the peat itself must have taken part in the fermentative changes.

It is of course, impossible to distinguish any very definite relationship between the figures just considered, owing to the fact that the errors attending them are too appreciable. I merely put them forward here to indicate, which we may safely take it they do with a fair approximation to the truth, the extent and real nature of the changes which occurred during fermentation in the solution.

The results recorded for the more dilute solution PA/20, in the first experiment 1*b*, are similar in character to those just considered. The volume of carbon dioxide formed, viz., 8·33 c.cs. (equivalent to 0·0045 grammes carbon) shows that the peaty matters must have been nearly completely fermented, as the quantity of carbon present before fermentation was 0·0055 grammes.

It is interesting to note, further, in reference to the results from both the dilute solutions, that the earlier steps of the fermentation which they underwent were almost entirely nitrous.

The second experiment, 2*b*, with the more dilute solution, shows a fixation of carbon dioxide and of ammoniacal or nitrous nitrogen, or both. The oxygen theoretically equivalent to the nitric nitrogen, assuming that it was derived partly from the nitrous nitrogen lost, and the remainder from the ammoniacal nitrogen, is 4·73 c.cs., while the volume actually consumed was 7·2 c.cs.

General Conclusions from Experiments with Solutions of Peaty Matters and Ammonium Compounds.

On reviewing the evidence afforded by the experiments recorded in Tables XIV. and XV., we may draw the following general conclusions as to the various phases of fermentation which may occur in solutions of peaty matters and ammonium compounds, in the presence of the mixed organisms natural to water, under varying conditions of dilution and relative proportions :—

1. When the proportion of peaty matters present is large, such that the organic carbon amounts to 0·1336 grammes per 1,000 c.cs. of solution, and that of ammonium compounds very small (such as 0·0079 grammes nitrogen as ammonia per 1,000 c.cs.), a fermentation may occur in which the ammonia is taken up presumably to form new compounds with the peaty matters, since the nitric acid formed is relatively very small, and since also because very decided volumes of carbon dioxide are involved.

The volume of oxygen consumed is decidedly in excess of that theoretically equivalent to the oxidised inorganic products formed during the fermentation.

2. When the same solution is decreased in strength by dilution, which is equivalent to increasing the proportion of oxygen, all other conditions remaining similar (except of course, that of mass), the fermentation may take a different course ; the volume of carbon dioxide formed becomes decided, and the ammonia becomes entirely absorbed as before, but the oxidised inorganic nitrogen product is practically exactly equivalent to the ammonia absorbed.

The oxygen consumed is practically equal to that theoretically equivalent to the inorganic oxidised products formed.

3. Only nitric acid appears to be formed in the solutions under the stated conditions.

4. When the quantity of peaty matters is not large in proportion to that of the ammonium compounds present in the solution (organic carbon being equal to 0·069 grammes, and ammoniacal nitrogen to 0·1 grammes per 1,000 c.cs.), a fermentation may occur during the earlier steps of which intermediate combinations between the peaty matters and the ammonia appear to take place, since during such stages the oxidized inorganic nitrogen compounds formed are not equivalent to the inorganic nitrogen taken up, while during a latter stage they are found to suddenly rise in quantity, and finally to become practically equivalent to it. Under these conditions the volume of carbon dioxide formed may be extremely small, relatively to that of oxygen consumed, or to the quantity of nitrogen oxidized.

The volume of oxygen consumed is, under these circumstances, very much less than that equivalent to the total oxidized inorganic products of the fermentation.

5. With the conditions stated under 4 we find that the nitrogen fermentation is both nitric and nitrous, the former predominating.

6. When the solution referred to under 4 is diluted, *i.e.*, when the proportion of oxygen is increased, the other conditions remaining similar, the course of fermentation appears to be much modified. From the first a large volume of carbon dioxide is formed, and the oxidized inorganic nitrogen is practically equivalent to the ammonia absorbed. When further, the fermentation is pushed to completion, both peaty matters and ammonia appear to undergo nearly complete oxidation to inorganic products.

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The volume of oxygen consumed is, under these conditions, also very much less than that equivalent to the total oxidized inorganic products of the fermentation.

7. It is interesting to note that the nitrogen fermentation in the dilute solution is both nitric and nitrous, the latter this time predominating, at least in the earlier stages of the fermentation.

For a further conclusion in reference to the subject, see p. 609.

RELATIONSHIP BETWEEN THE OXYGEN CONSUMED AND THE NITROUS ACID FORMED DURING THE FERMENTATION OF AMMONIA.

The experiments which have just been considered show that, when the fermentation of ammonia is carried on in the presence of peaty matters, the latter bodies take part in the fermentation, and prevent the true relationship between the oxygen consumed and the ammonia oxidized being seen. With the object of obtaining exact experimental data as to this point, I commenced a further series of experiments with a solution of ammonium chloride in distilled water, to which a little potassium phosphate and sodium carbonate were added, but no organic matter.

Some five litres of this solution were seeded with a few drops of the mixed sediments from the solution of peat (P/9), remaining in bottles II. and III. after the conclusion of experiment 5, recorded in Table XIV. I hoped by this solution to determine accurately the relation between the oxygen consumed and the nitrous acid formed, during a purely nitrous fermentation, carried on in the absence of peaty matters.

At the same time, in order to be able to compare the results of this experiment with those which would follow a fermentation by similar organisms in the presence of peaty matters, I started two further experiments with portions of the same peat solution remaining in the same bottles II. and III. To one portion I added a known quantity of ammonium chloride; to the other a known quantity of potassium nitrite. I had a further object in commencing these experiments, which I will describe later on.

The details and results of these experiments are given in the subjoined Table:—

TABLE XVI.—*Experiments to determine the relationship between the Oxygen consumed and Nitrous acid formed during the fermentation of Ammonia.*

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
1	July 23, 1894	Solution in distilled water containing a known quantity of ammonium chloride, and small quantities of potassium phosphate and sodium carbonate, but no added organic matter, seeded with a few drops of the mixed sediments from the solution of peat left in bottles II. and III. after the conclusion of experiment 5, recorded in Table XIV. - - - -	32·96	6·48	12·94	0·0225	0·0	0·0
	Oct. 25th ,,	Same after fermentation -	32·72	0·0	12·91	0·020	0 00224	0·0
		Differences - - - -	–0·24	–6·48	—	– 0·0025	+0·00224	—
1a	,, 26th ,,	Remainder of solution from preceding experiment, aerated -	31·52	7·13	14·03	0·019	0·00224	0·0
	March 23, 1895	Same after fermentation bottle I.	31·25	0·04	13·87	0·016	0·00464	0·0
	,, 26, ,,	Ditto Ditto ,, II.	31·40	0·06	13·95	0·016	0·00472	0·0
		Differences - - I.	–0·27	–7·09	—	–0·003	+0·00240	—
		,, - - II.	–0·12	–7·07	—	–0·003	+0·00248	—
2	July 24, 1894	1,000 c.cs. of the mixed peat solutions remaining in bottles II. and III. from experiment 5, Table XIV., diluted with 2,000 c.cs. distilled water containing a known quantity of ammonium chloride - -	11·04	6·72	13·19	0·0045	0·0	0·0001
	Nov. 25, ,,	Same after fermentation -	10·92	0·0	13·38	0·0015	0·00016	0·00284
		Differences - - -	–0·12	–6·72	—	–0·003	+0·00016	+0·00274
3	July 25, ,,	1,000 c.cs. of the same peat solution mixed with 2,000 c.cs. of distilled water containing a known quantity of potassium nitrite - - - - - -	11·05	6 72	13·19	0·0	0·0165	0·0025
	Nov. 30, ,,	Same after fermentation - -	10·99	0·0	12·98	0·0	0·0016	0·0164
		Differences - - -	–0·60	–6·72	—	—	–0 0149	+0 0139

Experiments 1 and 1*a* show that for the consumption of 6·48, 7·09, and 7·07 c.cs. of oxygen, 0·00224, 0·0024, and 0·00248 grammes of nitrous nitrogen were formed respectively.

If we raise these volumes each to 10 c.cs., for convenience of comparison, then the quantities of nitrous nitrogen formed would be, respectively, 0·00344, 0·0033, and 0·00351. That is for 10 c.cs. (=0·1437 grammes) of oxygen consumed, we have, taking the mean of these last three quantities, 0·00342 grammes of nitrous nitrogen formed. In other words, the formation of one part by weight of nitrous nitrogen is accompanied by the consumption of about 4·2 parts by weight of oxygen.

The volume of oxygen theoretically equivalent to the last-mentioned quantity of nitrous nitrogen, viz., 0·00342 grammes, on the assumption that it is derived from ammonia, is 8·14 c.cs.

Thus it will be seen, as was only to be anticipated, that during the fermentation of ammonia in the absence of all organic matter, the volume of oxygen consumed is in excess of that theoretically equivalent to the nitrous acid formed, in the proportion of 10 : 8·14.

On turning to the result of the experiment with ammonium chloride and peaty matters, the influence of the latter on the former, during fermentation, is shown in a most marked manner. Thus, not only is the quantity of nitrous and nitric acids greater in the presence than in the absence of these substances, but the product of oxidation is almost entirely *nitric acid* and not nitrous acid, as in their absence; the oxygen consumed being much the same in both cases.

If we raise the volume of oxygen, viz. 6·72 to 10 c.cs., for convenience of comparison with the results from experiments 1 and 1*a*, and the nitrous and nitric nitrogen in the same proportion, we find that for 10 c.cs. of oxygen consumed, 0·00024 grammes nitrous and 0·00408 grammes nitric nitrogen would be formed. These two weights are theoretically equivalent, on the assumption that they were both derived directly from ammonia to 0·5036 and 13·02 c.cs. of oxygen, respectively.

We see from these figures that, when peaty matters are present with the ammonium compounds the volume of oxygen consumed during fermentation, instead of being *larger*, is decidedly *less* than that equivalent to the ammonical nitrogen oxidized. These results then confirm those recorded in Table XV.

To consider now the determinations of the carbon dioxide. These show that, although the peaty matters must have so largely entered into the chemical changes set up during fermentation in this experiment, *no carbon dioxide was formed*, and it is extremely doubtful whether any was fixed, the difference recorded in the Table being possibly due to experimental errors.

It is possible also, since the ammoniacal nitrogen absorbed during the experiment was slightly in excess of the total nitrogen oxidized, that none of the latter was derived from the peat.

With reference to the question of the source of oxygen, the hydrogen of the ammonia may not have been so completely oxidized to water during the fermentation, in the presence of peaty matters, as in the absence of all organic matter. Some at least of the ammonical hydrogen may have been taken up by the peaty matters, and an increased quantity of oxidized nitrogen would, no doubt, be the results.

But whatever the mechanics of the chemical changes may be, which go on during fermentation, when peaty matters and ammonia are present together, the influence of the those matters, one upon the other, cannot be doubted.

I have not hitherto referred to the loss of carbon dioxide shown by the experiments 1 and 1*a* with the inorganic solution, because, in each case, it is so small as to be scarcely distinguishable from experimental errors. The determinations recorded are important, however, in showing that the carbon fixed must be very small compared with the nitrogen oxidized, and therefore they add aditional evidence to that already given by Winogradsky, who showed, by a process of wet combustion, that the assimilation of 1 part of carbon was accompanied by the oxidation of about 35 parts of nitrogen as ammonia to nitrous acid. The mean of the losses of carbon dioxide shown by experiment 1*a* is 0·15 c.cs., which is equivalent to 0·00008 grammes carbon, the ratio of the mean of the two quantities of nitrous nitrogen, recorded for the same experiment, viz., 0·00244 grammes, is as 1 : 30·**5**. These figures, it need hardly be said, are simply put forward here as confirmation of those given by Winogradsky.

In some of the preceding experiments, as I have before said, it appears that very definite volumes of carbon dioxide have been fixed, presumably during the formation of organic matters, but in all these experiments either peaty matters or fermented animal organic bodies, or, in the case of these latter, it should perhaps be said, both, as tap-water was employed for them, were present during fermentation.

Thus, the experiment with diluted sewage-water, S_2, recorded on page 581, shows a loss of as much as 0·77 c.cs., with a consumption of 7·6 c.cs. of oxygen, and the formation of only 0·00122 nitric nitrogen, and this experiment was carried out with extreme care, and it may be taken that the errors affecting the determinations are not seriously appreciable, since the quantities determined were small.

It appears then that peaty matters (and also fermented animal matters) influence the quantity of carbon dioxide which may be fixed during a fermentation of ammonia.

Referring now to the experiment (3) with potassium nitrite, it will be seen that as in the case of experiment (2) with ammonia and a portion of the same solution of peat, no carbon dioxide was either formed or fixed, so far as analysis could detect, The volume of oxygen theoretically required to oxidize the quantity of nitrous nitrogen which was converted during fermentation to nitric acid, viz., 0.0139 grammes, is 11·12 c.cs., a volume much in excess of that actually consumed (6·72 c.cs.)

It is impossible to suppose that this large excess of oxygen was derived from the quantity of peat present. Possibly intermediate combinations were formed during fermentation between the peaty matters and the nitrous acid, and that part at least of the nitric acid found after fermentation was formed from these combinations.

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Unfortunately I have not yet been able to determine the relationship between the oxygen consumed and the nitrous nitrogen oxidized during this fermentation of nitrites in purely inorganic solution, a fermentation which Warrington has shown to be possible, by conclusively proving that nitric organisms develop in solutions containing nitrites and the necessary inorganic salts only.* Winogradsky, it should be observed, has confirmed this. I trust, however, in a future communication to give the results of some experiments I have already commenced with a view of determining this point, together with the results of a further study on the fermentation of peaty matter and ammonia, upon which I am at present engaged, with the object of completing the work of which the experiments I have given can only be regarded as forming the commencement.

Before concluding my references to the experiments recorded in Table XVI., I should like to draw attention to the results from experiment 2, as compared with those afforded by experiment 1*a*, and recorded in Table XV. Those of the former experiment show an almost pure nitric fermentation, unaccompanied by either the formation or fixation of carbon dioxide, while those of the latter experiment show that the fermentation was a purely nitrous one, accompanied by the formation of a large volume of carbon dioxide. And yet in both dilute solutions of peat were employed, and each contained a decided excess of ammonia after fermentation. There was however, one distinct difference between the two solutions. The peat solution employed for the experiment recorded in Table XVI. had undergone several stages of fermentation before being employed for this experiment, while the solution of peat employed for the other was a comparatively fresh one. We may therefore add an additional conclusion to those already drawn, viz., that the changes which peaty matters may undergo in the presence of decided quantities of ammonia during fermentation may vary with their nature, *i.e.*, whether they have themselves undergone fermentation previously or not (see p. 604).

NITRIFICATION OF PURE UREA: AN EXCEPTION.

As I have shown in the earlier part of this Paper, easily fermentable nitrogenous organic matter, when attacked by water-organisms under continued aërobic conditions, suffer two distinct stages of change, first the organic carbon is nearly completely oxidized to carbon dioxide, and the organic nitrogen converted into ammonia; second, the ammonia thus formed is oxidized to nitrous or nitric acid.

That urea, when mixed with other organic substances, shows no exception to this rule has been proved by the researches of Warrington and of Munro, and also of other observers; the last named observer has shown, indeed that when this substance is mixed only with such a simple body as potassium oxalate,† the course of fermentation proceeds as above described.

The experiments which I have to describe were, however, made with simple solutions of urea in tap-water, containing in addition only a little sodium carbonate and potassium phosphate.

These experiments were commenced with two objects in view—(1) to ascertain whether nitrogen is evolved during the carbon stage of fermentation of urea, (2) to determine the nature of the nitrogen fermentation, which, it was anticipated, would follow the carbon fermentation.

The experiments were commenced in January, 1893, but the solutions were not examined again until nearly two years afterwards, and I was then surprised to find that even in a comparatively strong solution, containing as much as 0·05 grammes of urea per litre, a quantity of *nitrous nitrogen*, equal to 0·0016 grammes, had been formed, although it was apparently evident from the volume of carbon dioxide formed produced, at the same time, that not more than half the organic carbon originally present in the solution had been converted into that gas. It was feared, at first, that this was due to some leakage which might have occurred between the stopper and neck of the bottle in which the solution was preserved.

Accordingly, another set of experiments with urea was started, but this time with stronger solutions. A similar quantity of nitrous nitrogen was, however, again found, after fermentation, in a solution containing *ten* times the quantity of urea.

It accordingly seemed evident that urea, when *unmixed with other organic substances*, does undergo a change from the very commencement of fermentation, which apparently differs essentially in character from that of other easily fermentable organic substances so far as they are known. In the annexed Table will be found the particulars and results of the experiments above referred to.

EXPERIMENTS COMMENCED JANUARY 4TH, 1893.

TABLE XVII.—*Experiments with Urea.*

Solution U contained 0·25 grammes urea = 0·05 grammes carbon, and 0·116 nitrogen ⎫
0·10 sodium carbonate, ⎬ per litre.
0·10 potassium phosphate ⎭

Date of conclusion of experiment.	Solution.	CO_2 I.	CO_2 II.	O_2 I.	O_2 II.	N_2* I.	N_2* II.	N as NH_3 I.	N as NH_3 II.	N as N_2O_3 I.	N as N_2O_3 II.	N as N_2O_5 I.	N as N_2O_5 II.
1894. Dec. 29 -	U/5	7·45	16·56	8·40	0·0	16·72	16·50	0·0	0·009	0·0	0·0016	0·0001	0·0002
	Differences	+9·11		−8·40		...	...	+0·009		+0·0016		+0·0001	
,, 24 -	U/15	4·99	11·92	8·40	0·0	16·72	16·54	0·0	0·005	0·0	0·00288	0·0001	0·0012
	Differences	+6·93		−8·40		...	...	+0·005		+0·00288		...	...
,, 24 -	U/20	4·68	10·29	8·40	0·0	16·72	16·49	0·0	0·003	0·0	0·0014	0·0001	0·0019
	Differences	+5·61		−8·40		...	...	+0·003		+0·0014		+0·0018	
,, 28 -	U/40	4·22	7·49	8·40	0·0	16·72	16·51	0·0	trace	0·0	0·0016	0·0001	0·0021
	Differences	+3·27		−8·40		...	...	...	...	+0·0016		+0·0020	

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* Warrington: "Researches on Nitrification, C.S.J.; vol. lix., p. 519.

† *Loc. cit.*, p. 640.

Experiments commenced January 8th, 1895.

Further Experiments with Urea.

So'ution U′ contained 0·5 grammes urea = 0·10 grammes carbon, and 0·233 grammes nitrogen, } per litre.
0·02 sodium carbonate,
0·10 potassium phosphate,

1895.													
Mar. 19 -	U′	8·06	17·54	8·46	1·75	16·83	16·88	0·0	0·006	0·0	0·0016	0·00 1	0·0002
	Differences	+9·48		− 6·71		...	...	+0·006		+0·0016		+0·0001 ?	
,, 21 -	U′/5	5·74	20·89	8·36	0·0	16·60	16·83	0·0	0·016	0·0	0·00208	0·0001	0·0002
	Differences	+15·15		− 8·36		...	...	+0·016		+0·00208		+0·0001 ?	
,, 21 -	Tap-water	5·11	5·16	8·46	8·44	16·87	16·83	0·0	0·0	0·0	0·0	0·0001	0·0001

We have unmistakable evidence in the above results, especially those afforded by the solutions U′ and U′/5, *that nitrous acid is formed in decided quantity simultaneously with ammonia, from the very commencement of the fermentation of urea, under aërobic conditions, and in the presence of the mixed organisms of a natural water.*

The results recorded for the solution U′ are particularly instructive, because since a small quantity of dissolved oxygen was found in the solution at the conclusion of the experiment, it may be taken for granted that the fermentation therein proceeded throughout its course, so far as it went, under aërobic conditions.

Under these conditions we find that the nitrous nitrogen formed was practically one-fourth the quantity of ammoniacal nitrogen produced at the same time, the former amounting to 0·0016 grammes, and the latter to 0·006 grammes.

The volume of carbon dioxide, viz., 9·48 c.cs., equal to 0·005 grammes carbon, which was simultaneously formed with these quantities of nitrous and ammoniacal nitrogen, is not in atomic proportion therewith, but is equivalent, it will be found, to a quantity of carbon much greater than such proportion would allow. It must, therefore, have been derived, in part at least, from some intermolecular changes set up in the portion of the urea fermented. If the composition of these bodies, or body, were known, we should then have, with the results recorded in the above Table, all the factors required for the precise formulation of the changes which urea undergoes during fermentation under the conditions given.

The study of this fermentation of pure urea by the method here employed became, in fact, of very great interest. To what, for instance, is this formation of the nitrous acid during the first-stage fermentation of urea analagous ?

Is it analogous to the formation of the same body during true nitrification ? I am inclined to think not. It is rather, I should say, to be classed with the oxidized organic bodies which we know are formed during the first-stage fermentation of more highly carbonated compounds, the nitrogen in the said nitrous acid substituting carbon and this being possibly owing to the very small quantity of carbon contained in the urea, and to the chemical characters thereof. Before, however, this and other points suggested by the above experiments can be decided, a much more extended investigation will be necessary, and this I hope to commence shortly.

The fermentation in the solution U′/5 appears from the results recorded for it, to have proceeded further than in the solution just considered. A larger volume of oxygen was consumed, and a relatively larger quantity of nitrous nitrogen was formed. The carbon dioxide and ammonia were also increased, and in such large proportion that an anaërobic fermentation must, no doubt, have partially set in during the experiment.

Nitric Fermentation in Solution of Urea.

Turning once more to the results recorded in Table XVII., we notice that those afforded by the more dilute solutions U/20 and U/40 show that decided quantities of nitric acid were formed, but that apparently the nitrous acid first produced did not suffer further oxidation. This nitric fermentation may, however, have been brought about by the peaty matters in the tap-water employed for making up the solutions, and it is possible that *nitric* fermentation would not have set in in their absence. This is a question, however, which I must leave to a further communication.

Similar Quantities of Carbon Dioxide formed by Fermentation in Solutions containing similar Atomic Proportions of Carbon, as Urea, and as Potassium Sodium Carbonate.

It is interesting to compare the results with the above two dilute solutions of U, with those obtained from the dilutions IV/40 and IV/80 of the solution of potassium sodium tartrate employed for experiments recorded in Table XI. These two sets of solutions contained similar quantities of carbon, the one as urea, and the other as tartrate. From the long time during which the solutions were kept, it may be taken that the peaty matter in the tap-water with which they were made up suffered fermentation as well as the added substances. It is interesting to observe, therefore, that the volumes of carbon dioxide in each set are similar one to the other. (See also Tables VII. and XII.).

It will also be noticed that in both sets the conversion into oxidized inorganic products of the fermentable substances originally present in the solutions must have been nearly quantitatively complete.

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The Theory of Nitrification.

It seems to have been established from the researches of a number of observers, more especially from those of Mr. Warington, Professor P. F. Frankland and Mrs. G. Frankland, Dr. Munro, and M. Winogradsky, that the nitrification effected by soil organisms is brought about by two species, one of which oxidizes ammonia to nitrates, while the other oxidizes nitrites to nitrates.

These observers found that it was easy to obtain a nitrous fermentation in solutions of ammonia containing certain inorganic salts, but practically no organic matter, by means of organisms cultivated from soil. The attempt, however, to obtain a nitric fermentation of ammonia under like conditions has, so far as I know, failed.

It was, however, perfectly well known that a nitric fermentation could be set up in inorganic solutions of ammonia, seeded by fresh soil. The question remained in obscurity until Warington in his last-published "Researches on Nitrification," already referred to, showed that he had, in the course of his work, obtained some mixed organisms, some of which at least produced neither nitrous nor nitric acid from ammonia, but which energetically converted nitrites into nitrates.

Warington showed further, that the presence of ammonia retarded the action of the nitric organisms on nitrites.

Winogradsky has since isolated, from soil cultivations, the organisms which have the power of fermenting nitrites to nitrates in inorganic solutions.

On referring to the experiments which I have recorded on the fermentation of ammonia in the presence of peaty matters, and also, indeed, to such of those of other observers as were carried out in the presence of fresh soil, which it must be remembered no doubt contained organic bodies of a similar character and influence, in the shape of humus, to the peaty matters of my experiments, one cannot but be struck with the apparently direct influence of these matters on the fermentation. Thus, in the experiments 2, 3, 4, and 5, recorded in Table XV., the solution employed for which contained a large quantity of ammonia chloride relatively to the peaty matters, but in which the peaty matters were present in decided quantities, the nitric fermentation predominated, notwithstanding the fact that a considerable quantity of ammonia remained after the last experiment, No. 5; while with the more dilute solution in which the ammonia, so far as the fermentation was concerned, still remained large in quantity, but in which the peaty matters might be considered small in their relation to that of the ammonia, we get the reverse action shown, and the nitrous fermentation is seen to have predominated.

Again, if we refer to the experiments recorded in Table XVI., we find three solutions, all seeded with similar organisms, but differing markedly in other essential conditions:—

No. 1 is a purely inorganic solution, and in it a purely nitrous fermentation took place.

No. 2 contained peaty matters, and in it not only was a nearly pure nitric fermentation obtained, but the oxidized inorganic nitrogen product, in proportion to the oxygen consumed, was decidedly larger than in the case of solution 1.

Again, in solution No. 3, a nitric fermentation of nitrous acid is shown, in which the oxidized nitrogen product is, as in the case of the solution No. 2, theoretically equivalent to a much larger volume of oxygen than that actually consumed.

Here then, with the common condition of similar organism established in each solution, we get, in the absence of peaty matters, nitrous fermentation of ammonia, while in their presence we get a nitric fermentation of either ammonia or of nitrous acid.

The question therefore suggests itself—do not these peaty matters, when present in a water, exercise a dominating influence on the course of the fermentation of ammonia, and determine the nitric fermentation which is so noticeable concurrently with their presence?

I would go further and venture to suggest that the explanation of the observed fact—that the nitrification of ammonia in a mass of aerated soil results normally in the production of nitrates only (Warington)—is to be referred to the presence of organic substances in the soil, viz., humus, allied in character to the peaty matters of natural waters.

If this explanation be accepted, the question of nitrification would appear to stand thus:—

1. The nitrous organisms of soil thrive in inorganic solutions containing ammonia.
2. The nitric organisms of soil are gradually killed, or lose their vitality, in inorganic solutions containing ammonia.
3. The nitric organisms of soil thrive in inorganic solutions containing nitrites.
4. The nitrous organisms cannot oxidize nitrites to nitrates in inorganic solutions.
5. The presence of peaty or humus matters appears to preserve the vitality of nitric organisms during the fermentation of ammonia, and establishes conditions whereby it is possible for the nitric organisms to thrive simultaneously in the same solution with the nitrous organisms.
6. Query—Is it possible for either the nitrous, or nitric, or other organisms to separately set up the complete oxidation of ammonia to nitric acid, in the presence of peaty or humus matters?

Part III.—Bearing of the foregoing Experiments on the Analysis of Potable and Polluted Waters.

Up to the present time the bacteriological methods which have been proposed for the examination of waters have not resulted in bringing any very great practical assistance to bear on the subject of the technical examination of pure and polluted waters. I except, of course, those most important ones which can be employed for demonstrating the presence or absence of pathogenic organisms in a water. The suggestion that the number of microbes present in a given volume of water would give a useful indication or otherwise of its purity, from which so much was at first expected, has been shown, more especially in this country by the researches of Dr. P. F. Frankland,* to be of little practical value, except when applied for the examination of the efficiency of filtration, since many bacteria are capable of enormous and extraordinarily rapid multiplication even in waters of very high organic purity.†

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* "Proc. Roy. Soc.," 1886, p. 526.

† Article by Dr. P. F. Frankland, on "Water," already referred to, p. 990; see also work on "Micro-organisms in Water," by Dr. and Mrs. P. F. Frankland.

Bacteriological research has been instrumental rather, as I observed in the introduction to this Paper, in demonstrating the true agencies at work in setting up processes of oxidation in waters, and in thereby indicating new lines of research for completing our knowledge of the chemistry of natural and polluted waters.

The experiments which have been described in this Paper may, I venture to hope, prove a step onward in this direction, since they clear up, on the one hand, certain points in reference to the analysis of potable waters which have hitherto been more or less obscure ; and, on the other hand, they indicate a satisfactory method for the examination and analysis of polluted waters.

First, as regards the examination of potable waters, these experiments show conclusively that (1) the absence of easily-fermentable matters of all kinds, and (2) the indication that the water has been subjected to efficient artificial or natural filtration, are two conditions, positive evidence of which it is of the first importance to seek for in all waters to be used for dietetic purposes.

Broadly speaking, the first condition will have been established if the water contains no free ammonia, or only small traces of this substance, since of the easily-fermentable substances found in waters it is the last to be fermented.

The second condition will, no doubt, have been established if, in addition to the absence of free ammonia, traces only of organic matter (fermented) are found in the water.

In reference to this point it must be remembered that during efficient filtration all but traces of peaty or humus matters are separated. Hence, the absence of all but traces of these matters and of ammonia may be accepted as one proof of efficient filtration in water.

That efficient filtration of all water to be used for dietetic purposes is a prudent precaution in the interests of health must be accepted from the property which bacteriologists have shown properly-constructed filters to possess, of separating pathogenic organisms from water (Koch on Cholera, 1894).

It will be observed that the above two conditions in first-class potable water may be ascertained by the methods in ordinary use for water analysis.

In cases of doubt or suspicion, however, a careful examination of the character of the organic matters present should be made.

There can, I think, be no question that the method I have employed is capable of revealing both the nature and amount of polluting matters, should they be present in a water, or of proving their absence if not present. I can state from my own experience that examinations of such suspicious waters have afforded me results which have left no doubt in my mind as to their suitability or otherwise for dietetic purposes.

When we turn to the consideration of polluted waters, the matter assumes an entirely different aspect, for it is quite evident from the experiments which I have described, that the methods of analysis of potable waters, when applied to that of polluted waters, are not only quite incapable of indicating the true character of the polluting matters, but that they may even lead to absolutely misleading results.

From the experiments with polluted waters which I have recorded, it may be gathered that it is essential, in order to predict the action which a given volume of a particular polluted water will exert, when discharged into a watercourse of known volume and flow, to determine beforehand the exact volume of atmospheric oxygen which will be required for the complete fermentation of the polluting matters present, and that it is necessary also for technical purposes to approximately determine what fraction of that volume of oxygen is required for the first stage of fermentation of these matters. Under no circumstances ought a polluted water be discharged into a watercourse in such volumes that the dissolved oxygen in the mixture of the two waters, pure and polluted, is not more than sufficient to supply that required for the first-stage fermentation of the polluting matters.

This I consider is necessary, because the first stage of fermentation of easily-fermentable organic matters proceeds much more rapidly in a water exposed to the atmosphere than does the solution and diffusion of atmospheric oxygen through the water. Hence, if the quantity of dissolved oxygen of a water is insufficient for the needs of this stage of fermentation of any polluting matters in it, putrefactive fermentation will set in.

It is otherwise with the second-stage fermentation of a polluted water, since this stage of fermentation probably does not proceed so rapidly in a water exposed to the same conditions as the diffusion of atmospheric oxygen into it, and since, if it does, secondary products of a poisonous nature, such as are formed during putrefaction, cannot be simultaneously formed with nitrous or nitric acid from the very nature of the process of nitrification.

It is right, therefore, in dealing with the question of the pollution of a watercourse, to make this distinction between the oxygen required for the first-stage fermentation and that required for the second-stage.

I have made these remarks more particularly with the view of drawing attention to the possibility which the method of observation I have employed in this investigation presents, of formulating definite standards of impurity which should be allowed in the case of drainage waters discharged into a watercourse; it being possible, it should be observed, to formulate a standard according to local conditions and requirements.

A simple standard, which Local and River Conservancy Boards could control, could be framed as follows :—

The limit of impurity to be allowed to a given water to be such that, when a given volume of it is mixed with a given volume of tap- or other good water, and the mixture kept in a bottle out of contact with air, under the conditions I have described, for a sufficient length of time, a decided oxidation of the ammonia originally present in the mixture into nitrous, or nitric, acid shall be indicated.

This is, however, merely a suggestion. Were the principle of the proposed standards adopted, experience would show how best to formulate them.

GENERAL CONCLUSIONS.

Dr. Adeney.

The following conclusions may be drawn from the experiments recorded in this Paper:—

1. That the method and apparatus described in the Paper for preserving natural waters, or artificial solutions, out of contact with air, and for analysing the gases in solution in them, before and after keeping, are capable of yielding very accurate results, and that the method is not attended with any great experimental difficulties.

2. That observations of the changes in composition of the gases in solution, which take place during the course of fermentation in the presence of mixed organisms, under the conditions described, when made in conjunction with an examination of the changes which simultaneously occur in the organic and inorganic nitrogenous bodies in the water, are productive of extremely important results, and are necessary if it be desired to investigate completely the chemical changes which accompany such fermentations.

3. That with the aid of such observations it is possible to study the various chemical changes which take place progressively during the fermentation within certain well-defined conditions of any fermentable substance or substances, from commencement to completion, at any intermediate step desired.

4. That it hence becomes possible to demonstrate that the fermentation of substances under aërobic conditions by the organisms usually present in water, takes place progressively in two distinct stages: (1) that in which the organic substances are completely broken down, the carbon and nitrogen being largely converted into carbon dioxide and ammonia, a little organic matter remaining as such, but in an altered form; and (2) that in which ammonia is oxidized to nitrous or nitric acids, or both.

5. That the first stage of fermentation must be complete before the second stage can set in.

6. That the *organic* substances which result as products of the first stage of fermentation, may undergo further change during the subsequent stage, and give rise to the formation of carbon dioxide, and possibly also to nitric acid.

7. That peaty matters when present alone in a water undergo very slow change, but when present with ammonium compounds, they readily undergo fermentation together with the ammonium compounds, just as the organic matters which, as above stated, are formed during the first stage of fermentation of animal, vegetable, or artificial organic substances, do during the after fermentation of ammonium compounds which may have been also formed thereby, or which may have been previously present or added.

8. That the presence of the above-mentioned fermented organic matters, or peaty matters, appear to determine the *nitric* fermentation of *ammonia*, since in their complete absence, similar organisms being present, only nitrous acid is obtained.

9. That during the intermediate stages of a fermentation of mixed peaty matters and ammonium compounds, various interchanges between the two appear to take place, the character and extent of which apparently depend upon the relative quantities of peaty matters, ammonia, and dissolved oxygen present, and also upon the character of the peaty matters themselves, whether they have been freshly formed, or have undergone any previous fermentative changes.

10. That in the presence of small quantities of peaty, or other fermented organic matters, carbon dioxide and ammonia may become "fixed," during fermentation in appreciable quantities, no doubt from Winogradsky's researches to form organic matter.

11. That the formation of one part by weight of nitrous nitrogen during the fermentation of ammonia, in the complete absence of organic matter, is attended by the consumption of about 4·2 parts by weight of oxygen.

12. That for similar volumes of oxygen consumed, the quantity of nitrogen oxidized during the fermentation of ammonia is distinctly greater, in the presence of peaty or other fermented matters during fermentation than in their absence.

13. That for similar volumes of dissolved atmospheric oxygen consumed, the quantities of carbon dioxide and ammonia "fixed" are also more appreciable in the presence of those organic matters during fermentation, than in their absence.

14. That from the earliest stages of an aerobic fermentation of a strong solution of pure urea, containing no other easily fermentable organic substances, *nitrous* nitrogen is formed in addition to ammoniacal nitrogen, in the proportion of about 1 : 4. It is possible that the chemical changes which here result in the formation of nitrous acid are not analogous to those attending the formation of nitrous acid in the fermentation of ammonia, but rather to those attending the formation of the oxidized organic matter during a first-stage fermentation, the nitrogen, in the case of urea, taking the place of the carbon in a more highly carbonated organic compound.

15. That by determining the changes in the dissolved gases, and in the organic and inorganic nitrogenous compounds, which accompany fermentation in natural and polluted waters, it is possible not only to differentiate easily fermentable from difficultly fermentable substances present, but to approximately estimate their quantity.

16. That such determinations are of a very great value in the case of polluted waters, because in addition to affording very accurate estimations of the total quantities of fermentable matters in them, in terms of the exact volume of atmospheric oxygen necessary for their complete fermentation, it is possible by proper examination to determine what fraction of such volume is required for the first stage of fermentation, and what fraction for the second—distinctions of the utmost importance in considering the technical aspect of the pollution of rivers.

17. That in the course of the first-stage fermentation of some sewage-waters there is some evidence to show that appreciable quantities of atmospheric nitrogen may be fixed.

Before concluding this portion of my study, it is due to my friend, Mr. James Carson, Assoc. R.C.Sc.I., to acknowledge the most valuable services which he has rendered me during the whole time I have been engaged upon this investigation. He has not only assisted me throughout in carrying out the very laborious analytical determinations incidental to the work, but has further assisted me by making and perfecting the mechanical arrangements of the beautiful model of my gas-analysis apparatus, which is described in this Paper.

Enclosure II. to Dr. Adeney's Reply.

Dr. Adeney.

THE COURSE AND NATURE OF FERMENTATIVE CHANGES IN NATURAL AND POLLUTED WATERS, AND IN ARTIFICIAL SOLUTIONS, AS INDICATED BY THE COMPOSITION OF THE DISSOLVED GASES.

(Part IV.)—Humus; its Formation and influence in Nitrification. By W. E. ADENEY, Assoc. R.C.Sc.I., F.I.C., Curator in the Royal University, Dublin.

INTRODUCTION.

In this continuation of my studies of the changes in composition of dissolved gases which accompany bacterial fermentations in waters, I propose to detail and discuss some experiments with certain organic substances which belong to the class termed in my previous communication difficultly fermentable substances, to distinguish them from the class of substances which readily undergo fermentation in the presence of the micro-organisms ordinarily present in air and water, to which class most of the remaining known organic substances, with the exception of antiseptics, probably belong.*

The organic substances which may be included under the heading of "difficultly fermentable" are those found in good natural waters, and also those to be found in sewage, or other polluted waters, that have been subjected to complete fermentation under aërobic conditions, such as obtain during slow filtration through sand and soil.

I have already dealt with some of the latter forms of organic substances,† and also with some forms to be met with in natural waters, viz., peaty colouring matters.‡

The substances which have been employed for the experiments that I have presently to describe may be regarded as representative of the organic matters which occur in cultivated soils, and which find their way more particularly into well and spring waters.

Before proceeding, however, to the consideration of fresh experiments, it is desirable to decide upon the use of two new terms to indicate the two stages by which organic substances successively suffer aërobic fermentative change in waters, as described in my previous communications. During the first, an organic substance in solution is completely broken up; much the greater part of its carbon—about 90 per cent. in some cases§—is converted into carbon dioxide, and almost all its nitrogen into ammonia (with the one exception of *pure* urea, the nitrogen of which is partly changed into ammonia and partly into *nitrous* acid‖). A small quantity only of organic matter remains after the completion of this stage, and that in a very much altered form.

The characteristic feature of the second stage of change is the oxidation of the ammonia, which may have been formed during the first stage, or which may have been originally present in the form of an ammonium compound, to nitrous and nitric acids.

The organic matters resulting from the first stage of change also suffer a more or less complete oxidation in company with the ammonia during this second stage, and appear to play the important part of determining the final oxidation of the ammonia to *nitric acid*,¶ since when they are entirely absent—a fact now well known—the product of oxidation is *nitrous acid only.***

These organic matters also undergo a second stage of change *in the absence of ammonium compounds*; under these conditions, however, the change takes place extremely slowly; the products of the change are carbon dioxide and nitric acid.††

It is important to note, in reference to these organic products of a first-stage fermentative change, or, as we may call them, fermented organic matters, that, whatever changes they undergo, *they never give rise to the formation of ammonia.*

It has been suggested to me to employ the terms bacteriolysis or aërobiolysis for the first stage, and to restrict the use of the term nitrification to the second stage, of change. The restriction of the term nitrification to the use in this sense is, I think, most advisable, and I propose to employ it only in this sense in this and in future Papers.

It would also be convenient to adopt a simple word, such as bacteriolysis or aërobiolysis for the first stage of change; but, as my friend Professor W. N. Hartley, F.R.S., has pointed out to me, neither of these terms can be regarded as indicating with sufficient accuracy the true nature of the chemical changes which take place during its course. He has suggested that the terms carbon-oxidation and nitrogen-oxidation more accurately describe the two stages of change, on the grounds that the phenomena dealt with in these studies are really processes of decay or eremacausis, and that it is important that it should be clearly shown that no such change can take place in organic matters without heat evolution, whether brought about by the action of organisms, or by the action of fire; that is to say actual combustion.

The terms suggested by Professor Hartley have the great advantage of accuracy in their application, and, as a matter of fact, I occasionally used the terms carbon-fermentation and nitrogen-fermentation in a similar sense in my first Paper,‡‡ but hesitated to propose their general adoption, hoping that less cumbersome terms would suggest themselves after the publication of the Paper. In the absence, however, of such suggestion, I now propose to adopt the terms carbon-oxidation, and nitrogen-oxidation, or nitrification, to respectively denote the first and second stages of aërobic fermentative changes which form the subject of these studies. With the adoption of these terms, we may also adopt the classification of all fermentable bodies into (1) carbon-oxidizable bodies, or all fermentable organic substances which have not undergone carbon-oxidation; and (2) nitrifiable bodies, or ammonium compounds, and organic bodies which have suffered carbon-oxidation.

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* Trans. Roy. Dub. Soc. N.S., Vol. v., Part xi., p. 540, 1895.

† *Loc. cit.*, Tables V., IX., X., etc.

‡ *Loc. cit.*, Tables XIV., XV., and XVI.

§ *Loc. cit.*, Tables VII., VIII., XI., and XII.

‖ *Loc. cit.*, Table XVII.

¶ *Loc. cit.*, Tables III., V., VII., VIII., X., XIII., XV., and pages 587, 588.

** *Loc. cit.*, Table XVI.

†† *Loc. cit.*, Table XIV.

‡‡ *Loc cit.*, p. 610.

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Object of Experiments.

Turning now to the consideration of the experiments which I have to describe and discuss in this Paper—they have been made with the view of supplementing the information which I have already published upon the fermentative, and certain other, properties of the nitrifiable organic substances to be met with in natural waters.

These substances may be divided into three classes, according to their origin: viz. (1) the organic matters derived from the carbon-oxidation of fermentative organic substances in solution, *e.g.*, those present in most good river-waters; (2) those derived from peat, *e.g.*, those to be found in upland surface-waters; and (3) those derived from the organic matters or humus in soil, *e.g.*, those found in spring and well waters.

Classes 1 and 2 have been dealt with in Parts I. and II. of my first communication. I have now to take up the consideration of class 3, and I may add that, fortunately for my purpose, I have been able to employ a specimen of humus, the formation of which I knew beyond doubt to have been due to a true carbon-oxidation of fresh animal and vegetable solid refuse matters kept in a moist condition.

Origin of the Organic Matters (Humus) experimented with.

I have already made some reference to this humus in a short Paper published in the "Scientific Proceedings" of this Society.* It was found in some sewage sludge which had been allowed to ferment for some time under what were practically aërobic conditions. The sludge had been obtained from a sewage purification works, in which the coarser portion of the solid matters in suspension in the sewage were first separated by mechanical subsidence; the sewage was then mixed with a water solution of manganate of soda; the peroxide, which separated out, was allowed to subside, together with the matters remaining in suspension in the sewage, to the bottom of the tank in which the operation was conducted. It was finally drawn off from the tank in the form of a mud. I obtained several hundredweights of this mud, and first drained it on a gravel bed, and, when of sufficient consistence, I made it up into a large heap, and allowed it to slowly air-dry in a covered shed. After being left in this condition for about three months, I found the interior portions had assumed a grey colour, and were still wet and clay-like in consistence: only those portions of the heap immediately exposed to the air had retained the original brown colour of the peroxide.

Some small lumps were detached from different parts of the interior of the heap, and allowed to completely air-dry; an average portion was then analysed. The results of the analyses are given in the Paper above referred to (p. 250), and it will only be necessary to quote here the main results. They are:—

	Percentage.
Insoluble mineral matter and silica,	16·66.
Moisture,	15·68.
Organic matter, "soluble in HCl,"	4·35.
„ "insoluble in HCl,"	4·00.
MnO,	24·60.
$(NH_4)_2O$,†	0·005.
CaO, Fe_2O_3, Al_2O_3, MgO, Na_2O, K_2O, NiO, CoO, ZnO,	15·46.
CO_2	18·98.
$'SO_3$, $'P_2O_5$, $'Cl$,	0·96.
	100·695.

The above results show that the manganese was present as manganous carbonate: a careful examination was made for peroxide, but with negative results.

No trace of sulphuretted hydrogen, nor of other products of putrefactive fermentation, such as are met with when sewage solid matters alone are kept under similar conditions, were detected. An examination for nitrates was also attended with negative results.

Freshly-precipitated manganese peroxide is also rapidly reduced to manganous carbonate when it is kept immersed in comparatively large volumes of sewage water, in which bacterial fermentation is actively proceeding.

Reduction of Hydrated Manganese Peroxide in the Presence of Organic Matter due to Living Organisms.

I pointed out, in the Paper above referred to, that, when we consider the chemical characters of the peroxide of manganese, it seems impossible to avoid the conclusion that it owed its reduction to manganous carbonate, to the influence of some, at least, of the organisms which were abundantly present in the liquid with which it was saturated or immersed, and that the decomposition was analogous in character to that which Gayar and Dupetit‡ have shown nitre undergoes when it is present in a nutrient medium in which certain organisms are grown; and I showed, by means of thermo-chemical equations, that if the decomposition of the peroxide of manganese be thus regarded as the result of a fermentation, consisting of the direct oxidation of organic carbon at the expense of its available oxygen, the changes would be attended with considerable heat evolution, and would therefore constitute a considerable source of energy to the organisms.

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* "On the Reduction of Manganese Peroxide in Sewage," Vol. VIII., N.S. (1894), p. 247.

† The NH_3 in the wet mass, before complete air-drying, amounted to 0·014 per cent. (calculated on the wet mass, which contained about 60 per cent. moisture).

‡ "Ann. de la Science Agronomique," 1885, I., 226; also abstract "Chem. Soc. Journ.," XLIX., p. 823.

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We may now, however, take it for granted that the reduction of the moist peroxide, in the presence of organic matters, is the work of living organisms; for since the publication of my Paper referred to, my friend and colleague, Dr. E. J. McWeeney, has made the question a subject of bacteriological examination, and he has informed me that, in his experiments, in which he kept freshly-precipitated manganese peroxide in carefully-sterilized nutrient liquid media, no reduction of the peroxide was noticed, but that, in those experiments in which the nutrient media were seeded, after sterilization, with particles of the same fermented sludge as that with which I had worked, a rapid and very abundant growth and development of living organisms took place in the media; and at the same time it was noticed that the brown colour of the peroxide immersed therein was gradually and completely changed into a yellowish white. I subsequently examined this white substance myself, and found it to consist of manganous carbonate. I should add that the nutrient medium employed by Dr. McWeeney was a mixture of asparagine and rochelle salt, dissolved in distilled water, to which was added a little sodium phosphate and potassium chloride.

We may therefore regard the chemical change which took place in the mixed solid sewage organic matters and peroxide of manganese, in the mass above described, as a true carbon-oxidation of the organic matters, the available oxygen of the peroxide affording the necessary supply of that gas to the living organisms, just as the dissolved atmospheric oxygen did in the solutions of the organic matter with which I carried out my experiments on carbon-oxidation of *soluble* organic matters.*

I propose to give an experimental proof that the organic matters which resulted from this process of carbon-oxidation possess all the fermentative, besides the physical and chemical, properties which I have already shown fermented organic matters and peaty colouring to possess in common.

DESCRIPTION OF EXPERIMENTS UPON THE FERMENTATION OF THE HUMUS.

As will be gathered from the above Table of Analysis, a portion of the organic matters present in the sludge was taken up by the acid employed for dissolving out the soluble portions of the substance. Practically, however, all was left undissolved when the solution was evaporated to dryness, and the residue treated with hydrochloric acid, in the ordinary way, for the separation of silica if present.

The organic matters which were separated in this way were employed for the experiments I have to detail. They were brownish black in colour, and were slowly but completely soluble in a solution of sodium carbonate. The solution obtained was of deep brown colour, indistinguishable from an extract of peat or of garden soil similarly prepared. The ratio of organic carbon to nitrogen was 6·84 : 1. They were therefore similar in these particulars to the organic matters contained in the extract of peat employed for the experiments recorded in Part II. of my first Paper.†

I should add that the portions of the sludge which were undissolved by hydrochloric acid also yielded, on treatment with sodium carbonate solution, a deep brown solution. The details of experiments with this portion of the organic matters of the sludge I must, however, leave to a future Paper, should they prove to differ in fermentative properties, which, however, I do not anticipate. The ratio of organic carbon to nitrogen of the total organic matters in the fermented sludge was 7 : 1.‡

The experiments with the organic matters above described were carried out in accordance with the methods described in my first Paper. The analytical determinations, made before and after keeping the various solutions, employed for experiment, out of contact with air, are recorded in the following Table XVIII.

The first solution (*H*) was prepared by dissolving a known weight of the humus in distilled water and a little sodium carbonate; and when the solution was complete, a few drops of sediment from one of my old experiments with peat extract were added for the purpose of seeding, together with the necessary mineral salts, and the whole was diluted to the necessary bulk with distilled water.

The solution *H′* contained a similar quantity of humus in solution as *H*, but more sodium carbonate, and, in addition, ammonium chloride.

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* Professor W. N. Hartley, F.R.S., has recently published a short interesting paper on "The Cause and Nature of the Chemical Changes occurring in Oceanic Deposits," in which he points out that the chemical changes which take place between the organic matter and the mineral salts in fresh- and sea-water mud are to be ascribed to the action of well-recognized living organisms, and shows, by thermo-chemical equations that, at each stage of change, there is heat evolution.—Proc. R. S., Edinburgh, 1895–96, p. 25.

† *Loc. cit.*, p. 593.

‡ It should also be noted that an examination of wet portions of the fermented sludge was made at the time the above analysis was carried out, with the view of ascertaining whether there still remained in the sludge any organic matters which had not undergone complete carbon-oxidation. For this purpose, about 40 grms. of the sludge were saturated with 2 litres of water; and portions of the water, with the sludge matters in suspension, were transferred to bottles and preserved out of contact with the air for 21 days, according to the method I have described. On examination of samples (in which, of course, the matters in suspension had previously been allowed to completely subside), before and after keeping, indications of a considerable fermentative change were found The whole of the dissolved oxygen had been consumed during the period of keeping out contact with air, and a large volume of carbon dioxide formed; but inasmuch as no appreciable increase in the amount of ammonia, originally present, was detected, and the water remained perfectly free from unpleasant odour, or any other indication of putrefactive fermentation, it appeared evident that the fermented sludge, at the time I commenced my examination of it, contained only small quantities of organic matters that had not undergone complete carbon-oxidation. No nitrous or nitric acid was detected in these solutions, either before or after keeping.

Dr. Adeney.

TABLE XVIII.—*Experiments with Humus obtained by the fermentation of wet solid animal and vegetable matters in the presence of hydrated manganese peroxide.*

Solution H contained 0·0465 grammes organic carbon,
0·0068 „ „ nitrogen,
0·1 „ Na_2HPO_4,
0·1 „ KCl
a small quantity of $NaHCO_3$,
per litre.

[The gases are expressed in c.cs., measured at 0° C., and 760 mm. bar., the other constituents as parts by weight, per litre of water.]

No. of Experiment.	Date of commencement and of conclusion of Experiment.	Description of Experiment.	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5	Remarks.
	1896.								
1	Feb. 24,	Solution H, aërated,	16·73	7·52	15·30	·0002	0	0	Deep brown colour.
	Mar. 17,	Same after fermentation,	17·80	5·29	15·35	·0002	0	·0002	Ditto.
1*a*	July 20,	Another bottled portion after fermentation,	19·84	2·09	15·26	0	0	·0006	Ditto.
2	Feb. 24,	Solution H + AmCl = H_1,	16·73	7·52	15·30	·004	0	0	
	Mar. 2,	Same after fermentation,	17·23	6·52	15·2	·004	0	0 ?	
2*a*	„ 30,	Another bottled portion after fermentation,	18·19	4·81	15·33	·004	0	·0002 ?	
3	„ 16,	Solution H_1 diluted with distilled water, 1 : 9,	7·08	7·66	15·2	·0005	0	·0008	Faintly but distinctly coloured greenish yellow.
	1897.								
	Mar. 24,	Same after fermentation,	8·97	3·51	15·0	0	0	·001	Ditto.
3*a*	„ 25,	Another bottled portion,	8·51	3·66	15·08	0	0	·001	Ditto.
	1896.								
4	Mar. 31,	Remaining solution from Exp. 1 and 1*a* + more solution (H′) of Humus + AmCl (prepared Feb. 26); whole diluted with equal bulk of water = H_2,	24·09	7·77	15·48	·0024	0	·0004	Strongly coloured brown.
	July 21,	Same after fermentation,	26·49	0	15·34	·0001	·00112	·00078	Ditto.
4*a*	„ 23,	Another bottled portion after fermentation,	26·22	0	15·39	·00005	·00144	·00091	Ditto.
5	April 4,	Solution H_2 + AmCl, diluted with distilled water 1 : 6,	7·78	7·59	15·30	·0016	0	·0002	Faintly but distinctly coloured yellowish brown.
	July 25,	Same after fermentation,	7·72	1·16	15·13	0	0	·0018	Ditto.
	1897.								
5*a*	Jan. 5	Another bottled portion after fermentation,	7·65	0·98	15·16	0	0	·00195	Ditto.

Dr. Adeney.

The results of the experiments recorded in the previous Table will be more readily seen when expressed in a tabular form as follows:—

TABLE XIX.—*Showing quantitatively the fermentative changes which occurred in the composition of the dissolved gases, and of the inorganic nitrogen compounds during the experiments recorded in the previous Table.*

No of Experiment.	Duration of Experiment.	CO_2	O_2	N as NH_3	N as N_2O_3	N as N_2O_5
1	22 days - - - -	+ 1·07	– 2·23	—	—	+ ·0002
1*a*	5 months - - - -	+ 3·11	– 5·43	– ·0002	—	+ ·0004
2	7 days - - - -	+ 0·50	– 1·00	—	—	+ 0 ?
2*a*	35 days - - - -	+ 1·46	– 2·71	—	—	+ ·0002 ?
3	1 year - - - -	+ 1·89	– 4·15	– ·0005	—	+ ·0002
3*a*	1 year - - - -	+ 1·43	– 4·00	– ·0005	—	+ ·0002
4	4 months - - - -	+ 2·40	– 7·77	– ·0023	+ ·00112	+ ·0007
4*a*	4 months - - - -	+ 2·13	– 7·77	– ·00235	+ ·00144	+.00087
5	4 months (nearly) - -	– 0·06	– 6·43	– ·0016	—	+.0016
5*a*	9 months - - - -	– 0·13	– 6·61	– ·0016	—	+ ·00175

On examining the results recorded in the above Table it at once becomes apparent that the fermentative properties of the humus employed for the experiments are alike in character to those which I showed in my first communication were so characteristic of fermented organic matters and of peaty colouring matters, and to which I have already referred.

For example, in experiments 1 and 1*a*, in which the humus was present in comparatively large, and the ammonia in extremely small, quantity, we have a very slow fermentation, the products of which are carbon dioxide and nitric acid, which was partly derived from the nitrogen of the humus.

In experiments 2 and 2*a*, it is evident that the time allowed for fermentation was insufficient, and only a slight fermentative change is exhibited, resulting simply in the production of small volumes of carbon dioxide, the consumption of small volumes of oxygen, and the doubtful formation of a small quantity of nitric acid. In the succeeding experiments 3 and 3*a*, a part of the same solution as that employed for experiments 2 and 2*a*, and which was kept in a vessel freely exposed to the air between the dates February 24th and March 16th, was diluted, on date of experiment, with distilled water in the proportion of one volume of the former to nine of the latter and used. The results were the formation of small quantities of carbon dioxide, and of nitric acid, the consumption of a part only of the dissolved oxygen, and the disappearance of all the ammonia originally present.

In experiments 4 and 4*a*, it became necessary to employ, in addition to the portions of *H* which remained from previous experiments, some fresh solution of humus (*H'*), which had been prepared on February 26th previously, and had been kept since its preparation in a vessel freely exposed to the air. These experiments were made to examine the fermentative properties of the humus in the presence of a decided quantity of ammonia under more suitable conditions than experiments 2 and 2*a* were found to afford. In those experiments, the ammonia was present in unnecessarily large quantity, and prevented the certain detection of small quantities of nitric acid if formed. Accordingly, for experiments 4 and 4*a*, a less quantity of ammonia was taken, and a longer time allowed for fermentation. The results of these experiments showed that, when the dissolved oxygen was insufficient for the complete oxidation of the ammonia present, both nitrous and nitric acids may be formed, and small volumes also of carbon dioxide.

The conditions secured for the next and final experiments (5 and 5*a*) were arranged, so that oxygen should be present in just sufficient quantity for the complete oxidation of the ammonia, and in each experiment the oxidation of the ammonia to *nitric* acid was complete. These experiments also prove that a *nitric* fermentation of ammonia may be carried on in the presence of small quantities of humus, without any carbon dioxide being formed, there being some evidence (see 5*a* more especially) that a small quantity of carbon dioxide was actually "fixed." Abundance of evidence of a similar *nitric* fermentation, in the presence of both fermented organic matters and of peaty colouring matters will be found throughout my first communication.

These experiments afford additional evidence, to that I have already published, to the effect that organic matters, which are themselves the result of bacterial fermentative changes, or a carbon-oxidation of fresh organic substances, take an active part in any subsequent fermentation of ammonium compounds with which they may be mixed, and determine the *nitric* fermentation of those compounds.*

In addition they extend our knowledge nitrifiable organic substances to those which may be derived from cultivated soils, or, in other words, to the organic matters which may be more especially met with in waters that have passed through cultivated soils (spring and well waters); and they show that these organic matters in no way differ in general fermentative properties from those to be met with in waters holding peaty colouring matters in solution (upland surface waters), or from those to be met with in waters in which a complete carbon oxidation of the organic matters from past pollution by sewage, or other surface drainage waters, has taken place (most, if not all, good river waters).

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* *Loc sit.*, pp. 593-613.

Dr. Adeney.

We have, in fact, from these experiments, and those I have already published, fairly complete information as to the possible fermentative changes which the nitrifiable substances to be met with in natural waters, whether they be upland surface, well or spring, or river waters, may undergo.

These changes may be briefly summarized as follows:—

1. When the nitrifiable substances are freshly formed, and are present in comparatively large quantity in a water, the formation of a decided volume of carbon dioxide, in proportion to the volume of dissolved oxygen consumed, and the formation also of a quantity of nitrous or of nitric acid, or both, but in small quantities, may attend the earliest stage of fermentative change they may undergo.*

2. At subsequent stages the volume of carbon dioxide formed is not so large, and the inorganic nitrogen products, nitrous or nitric acid, become the more marked in quantity in proportion to the oxygen consumed.†

3. At a still later stage, at the completion of which all the ammonia becomes fermented, little or no carbon dioxide may be found, but, on the contrary, a little may become "fixed"; the inorganic nitrogen products consists then of nitric acid solely.‡

4. When little or no ammonia is present, *freshly* formed nitrifiable organic matters may undergo at first a slow change, during the first steps of which distinct volumes of carbon dioxide and of dissolved oxygen may be formed and consumed, respectively; small quantities of nitric acid are formed at the same time.§

5. But after these earlier steps of change the fermentation becomes slower, and finally becomes so slow as to be scarcely appreciable; still the results are the formation of carbon dioxide and nitric acid, and the consumption of a proportionately small volume of dissolved oxygen.‖

This brief summary of the fermentative changes which nitrifiable organic substances may undergo in the presence and absence of ammonia shows how definitely and easily this class of inorganic substances may be differentiated from unfermented or "carbon oxidizable" substances when both classes occur together in a water; and it emphasizes the point I put forward in Part III. of my first communication, viz., that the analysis of suspicious and polluted waters should always include an examination of the fermentative changes which may occur in the composition of the dissolved gases and of the inorganic nitrogen compounds contained in such waters—an examination which is easily made, when the waters are preserved in the manner and under the conditions I have described.

If, for example, a water be regarded as suspicious for potable purposes, on account either of its containing too much organic matter, or an abnormally large amount of ammonia, an examination of it by the methods I have employed in these studies will yield exact information, whether in the first case, any portion of the organic matters are in an unfermented condition or not, and, in the second, whether the ammonia will suffer rapid nitrification or not.

Information as to both these points are essential before a definite opinion can be expressed as to the suitability or otherwise of the water for potable purposes. Since a positive result in either case would definitely condemn the water for such use, for in the first case, very recent pollution would be indicated, while in the second case an abnormal bacterial activity would be revealed, which, in the light of recent bacteriological teachings as to the true functions of a filter, ought to be regarded as indicating insufficient filtration. As an example of this latter case, I may quote the examination of a water which recently came under my notice. An ordinary analysis showed that the water contained ammonia in somewhat excessive quantity, viz., ·016 parts (nitrogen as ammonia) per 100,000 of the water. It also yielded ·009 nitrogen as albuminoid ammonia per 100,000. The water was classed as suspicious, and I examined it for fermentative changes with the following results:—

	CO_2	O_2	N_2	N as NH_3	N as N_2O_3	N as N_2O_5
Before keeping	113·69	4·03	15·69	·00016	0	·0025
After keeping for 7 days . .	113·59	3·76	15·76	0	0	·0025
Fermentative changes . .	—	–0·33	—	–·00016	—	—

The constituents are expressed as in the previous Tables, viz., gases as c.c. at N. T. P., and nitrogen compounds as parts by weight, per 1000 c.cs. of water. It should be noted the water was slightly turbid, but contained no suspended matter. The results show the ammonia was completely taken up, and that a corresponding volume of oxygen was consumed during the seven days the water was kept, but that no carbon dioxide was formed. This comparatively rapid nitrification of the ammonia must have been due to a decided bacterial activity in the water. On subsequent inquiry it was found that cases of typhoid fever had occurred in the house supplied from the well.

When we turn to the consideration of polluted waters in reference to the question of the pollution of rivers, I think that it will be conceded that the experiments recorded in this and in my previous Papers, establish beyond question the desirability and necessity of including, in the analysis of such waters, a determination of the unfermented organic matters they may contain, in terms of the volumes of free oxygen and of carbon dioxide which will be consumed and formed, respectively, and also if they contain nitrogen of the ammonia which will be formed during their complete carbon-oxidation.

To complete the analysis of such waters, the volume of free oxygen consumed during the subsequent nitrification of the ammonia may be determined, but this, I believe, will be found unnecessary for technical purposes.

I trust shortly to be able to publish the results of some further experiments both in carbon-oxidation and in nitrification, the solutions for which have been preserved at blood-temperature in an incubator.

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[*] *Loc. cit.*, Table V., exp. 1; Table XIV., exp. 2; Table XV., exps. 1*a* and 1*b*.

[†] *Loc. cit.*, Table V., exp. 3; Table VIII.; Table XIII., exp. 7; Table XV., exps. 3, 4, 5, 2*a* and 3*a* also Table XVIII. (above), exps. 4 and 4*a*.

[‡] *Loc. cit.*, Table V., exp. 4; Table VII., exp. 6; Table X., exp. 3; Table XV., exp. 2*b*; also Table on p. 588: also Table XVIII. (above), exps. 5 and 5*a*.

[§] *Loc. cit.*, Table XIV., exp. 5.

[‖] *Loc. cit.*, p 561; Table IX., exp. 4; Table XIII., exps. 5 and 6; Table XIV., exp. 6; also Table XVIII. (above), exps. 1 and 1*a*, and 3 and 3*a*.

Enclosure III. to Dr. Adeney's Reply.

Studies in the Chemical Analysis of Fresh and Salt Waters.

(Part I.)—Applications of the Aeration Method of Analysis to the Study of River Waters. By W. E. Adeney, D.Sc., A.R.C.Sc.I., F.I.C., Curator, and Examiner in Chemistry, in the Royal University of Ireland.

I have recently had occasion to make some careful studies of non-tidal and tidal river waters, and it has occurred to me that a brief record of some of my results may prove of value at the present time, when the best methods of analysis of polluted waters is still a subject of inquiry and discussion.

Recent work upon this class of waters has all gone to emphasize the importance of distinguishing the unfermented organic matters from the fermented, and to estimate the proportion in which they exist, when present in a water.

I communicated a paper* to this Society some five years ago, in which I described a method of analysis, and the experimental investigation on which it was based, capable of effecting both these objects.

Dr. George M'Gowan has very appropriately termed it the "Aeration Method," and I propose to adopt this term.

The Aeration Method of Analysis.

Although I have published a detailed description of the method, it will perhaps prove convenient, if I give a brief outline of it here. The bottle in which the sample of water for analysis is collected is completely filled and carefully stoppered, so as to exclude every trace of air. The bottle is then conveyed to the laboratory without delay, and the sample is divided into two portions; the dissolved gases, and inorganic nitrogen compounds, are determined in one portion; the other portion is carefully preserved out of contact with air in the bottle into which it has been transferred, and which it completely fills. This is easily done by keeping the bottle immersed in water, neck downwards.

After keeping for a sufficient time, the dissolved gases and inorganic nitrogen compounds are determined as with the first portion, and the two sets of results give the means of determining quantitatively the changes in composition of the dissolved gases, and of the nitrogen compounds, brought about by the fermentative processes which the sample has undergone during the time it has been kept.

Advantages of the Aeration Method.

The advantage of the method was shown to be that it gave absolute results and not comparative, and determined with very great accuracy the amount of fermentable organic matter present in the water, in terms of the carbon dioxide, and of the ammoniacal, and (possibly) nitrous and nitric, nitrogen formed, and of the dissolved oxygen consumed by their complete aërobic fermentation, and that also it enabled a distinction to be drawn between the oxygen consumed in the fermentation of the organic matter, and that consumed in the fermentation, or nitrification, of the ammonia. The value of the method has been recognised by chemists having a special knowledge of the subject. It, however, necessitates the determination of the dissolved gases in a polluted water, both when fresh and after fermentation. This involves, of course, gasometric analysis; and gasometric methods have apparently been avoided where possible by analysts in water analysis as being too laborious.

Attempts have been made to obtain sufficiently definite results without the aid of gasometric methods of analysis, but I do not know that any of them have been followed with even partial success.

It was hoped that some definite relationship would be found to exist between the actual quantities of organic matters in polluted waters, and the "oxygen absorbed" by them from acid permanganate, and possibly also the "albuminoid ammonia" yielded by them with alkaline permanganate. Practical attempts, however, to establish such relationships have failed to realise this hope. The important paper† recently communicated to this Society by Professor Letts, D.Sc., and his pupils, gives some interesting experimental data, showing, amongst other results, that no relation exists between the oxygen actually consumed by the fermentation of the organic matters in a polluted water, and the "oxygen absorbed" from acid permanganate; and that albuminoid ammonia determinations likewise afford no definite information as to the character, or quantity, of the organic matters in a polluted water.

All the Dissolved Gases in a Water should be Determined, and not the Dissolved Oxygen only.

Some hope has also been entertained that simple determination of the dissolved oxygen in the water at the time of collection by one of the well-established volumetric methods might yield important information as to the condition of the water when collected, more especially in the examination of river waters for pollution.

It becomes obvious, however, upon reflection that such determinations, although capable of being made with great accuracy, can be of very limited value, since at best they must be liable to very serious errors when calculated into percentages of saturation in order to reduce them to a standard and comparable form, owing to the uncertainty as to the standard quantity of dissolved oxygen the water should contain, if unpolluted, when the only datum known in connection with the water at the time of collection is that of its temperature. I may here note that this difficulty does not arise in the aeration method, since the dissolved nitrogen is determined in addition to the dissolved oxygen, and this gives us the means of calculating the maximum quantity of oxygen which should be dissolved in the water at the time of collection.

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* Trans. R.D.S., N.S., Vol. v., Pt. xi., 1895.

† Scien. Proc. R.D.S., Vol. ix (N.S.), Pt. iii., p. 337.

Dr Adeney.

EXPERIMENTAL DETAILS OF THE AERATION METHOD NOT LABORIOUS.

The failure so far to discover a reliable method of analysis without the use of gasometric methods, induces me to again draw attention to the aeration method, and to illustrate its value by some practical applications, more especially as extended experience with the method has convinced me that it can be carried out with greater ease and more quickly than would be anticipated by chemists not practically acquainted with it. With the special apparatus described in my original paper (see also "Chemical News," vol. 62, pp. 196–199, and 204–206) for extracting, measuring, and analysing the gases dissolved in the water, and employing an extraction flask, of not less than 1,600 c.cs. capacity, and working with 100 c.cs. of a sample of water, I find that the dissolved gases may be extracted, measured, and analysed in six samples, one after another, easily within six hours, including the washing out of the Eudiometer and Laboratory vessel necessary between each analysis.

I am also induced to again draw attention to the aeration method, in that I am now prepared to describe a modification of it, whereby the "oxygen absorbed" by fermentation in a polluted water may be determined by a single gas measurement. A detailed description of this modification will shortly follow in Part II. of this Paper.

APPLICATION OF THE AERATION METHOD TO THE STUDY OF A SLIGHTLY POLLUTED NON TIDAL RIVER WATER.

The value of the aeration method is well illustrated by the results of analyses, recorded in Table I., on next page, of samples of a slightly-polluted non-tidal river water, viz., the river Liffey, from immediately above Chapelizod to the weir at Island Bridge.

The purpose of the examination of this water was to ascertain whether it was a safe water for out-door and strictly non-dietetic use.

The water is pumped up from a point just above the weir, and is stored in a large tank for the purpose of distribution.

Samples 1 and 2, Table I., were collected on the same day, September 21st, 1899, during dry weather. The first from immediately above the weir, and the second from the bottom of the distributing tank into which the water was being pumped at the time.

The ordinary analytical determinations recorded in Table I. cannot be regarded as indicating the existence of any fresh polluting matters in the water; the only conclusion that can in fact be drawn from them, is that the water is an excellent river water.

The composition of the dissolved gases, however, before and after fermentation, show a marked difference, and indicate, when, taken into consideration with the inorganic nitrogen compounds, the presence of very decided quantities of fresh organic matter in sample 1, and show also that the quality of sample 2 is much better than that of sample 1.

The difference in composition of the dissolved gases also affords the means of estimating exactly, the quantity and character of the polluting matters in each sample. No. 1 for instance is shown to have undergone a very decided fermentation on keeping, during which nearly the whole of the dissolved oxygen had been consumed; and the fermentative process is shown also to have consisted of both a carbon fermentation and a nitrogen fermentation.

We may also conclude from the relative proportions of carbon and nitrogen fermented that the unfermented organic matters, originally present in the water, were of vegetable origin.

The analysis of sample 2 shows that the fermentative process which went on in the sample, when kept, was almost entirely confined to a nitrogen fermentation, and that consequently but little, if any, unfermented organic matter was originally present in the sample.

The carbon fermentation in this sample had, no doubt, taken place during the time of storage in the distributing tank.

I ought, perhaps, to explain the particular meaning I attach to the terms "carbon fermentation," and "nitrogen fermentation," before proceeding further.

I have used these two terms to indicate the two progressive steps in which the bacterial fermentation under complete aërobic conditions of organic substance and of ammonia takes place.

The organic substances are first completely broken down, and oxidized almost entirely into carbon dioxide, water, and ammonia. Traces of oxidized organic matters are also formed, and these undergo a more or less complete further oxidation into carbon dioxide and nitric acid during the subsequent fermentative process of the oxidation of the ammonia into nitric acid. Thus during the first step of the fermentative process, the oxidation of the unfermented organic carbon is the main factor of the process; while the oxidation of the ammoniacal nitrogen into nitric acid is the main factor of the second step of the fermentative process; hence the terms "carbon fermentation" and "nitrogen fermentation" which I have employed. When the ascertained consumption of oxygen covers both fermentative processes, the loss due to each process may be calculated with sufficient accuracy for practical purposes on the assumption that the loss due to the nitrogen fermentation is equal to the volume of oxygen theoretically required for the direct oxidation of the quantity of ammonia found to have been oxidized by fermentation. (I have fully treated this question in my original Paper.*)

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* Trans. R.D.S., Vol. V., pp. 593–604.

TABLE I.—*Analyses of Samples of Water collected from the River Liffey above the Weir at Island Bridge, Co. Dublin.*

No.	SAMPLES.		Dissolved Gases expressed as volumes at N.T.P. per 1,000 volumes of water.			Other Constituents expressed as parts per 100,000 of the water.					
	Where Collected.	Description.	Carbon Dioxide.	Oxygen	Nitrogen.	Nitrogen as		Organic Nitrogen in		Chlorine.	Total Solids.
						Ammonia.	Nitrates.	Suspension.	Solution.		
1	Just above the Weir, near the right bank, September 21, 1899.	Slightly turbid, yellowish green tint; traces of suspended matter	58·78	5.25	14·34	·0040	·0340	·008	·052	1·26	—
	Ditto after keeping	37 days - - - - - -	62·13	0·88	14·25	·0015	·0385	—	—	—	—
2	From the bottom of the distributing tank, September 21.	Very slightly turbid, yellowish brown tint; traces of suspended matter - - - - -	60·54	5·48	14·11	·0045	·0375	·008	·0517	1·295	—
	Ditto after keeping	38 days - - - - - -	62·84	3·98	14·11	·0015	·0405	—	—	—	—
3	Just above Chapelizod, October 16.	Slightly turbid, brown colour; traces of suspended matter - -	41·38	7·49	15·55	·004	·027	·023	·029	1·205	18·0
	Ditto after keeping	15 days - - - - - -	42·12	6·54	15·45	·004	·035	—	—	—	—
4	Just below Chapelizod, October 16.	Similar to No. 3, but a little more turbid - - - -	41·01	7·63	15·52	·004	·028	·013	·045	1·26	18·0
	Ditto after keeping	17 days - - - - - -	42·68	5·20	15·59	·004	·037	—	—	—	—
5	Just above the Weir, near the right bank.	Distinctly turbid, olive green tint; small quantity of vegetable *debris* in suspension - - - -	43·47	5·98	15·52	·002	·026	·02	·081	1·26	18·4
	Ditto after keeping	15 days - - - - - -	48·61	1·06	15·38	·035	·011	—	—	—	—
6	From bottom of distributing tank, October 24.	Slightly turbid, yellowish green tint; traces of suspended matter	63·30	5·46	15·27	0032	·040	·02	·055	1·295	—
	Ditto after keeping	9 days - - - - - -	64·78	2·97	15·19	·0010	·044	—	—	—	—
7	Just above the Weir, near the right bank.	Slightly turbid, yellowish green tint; traces of suspended matter	72·64	3·23	14·93	·0028	·051	·02	·079	1·4	0·0
	Ditto after keeping	8 days - - - - - -	75·62	0·44	14·99	·0230	·035	—	—	—	—

The weather was dry both on September 21st and on October 16th; it had just commenced to break when sample 6 was being collected, and heavy rain had fallen before sample 7 was collected on the following day.

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The samples 3, 4, and 5 in Table I. were all collected on October 16th, and in dry weather. Their analyses again illustrate the very great value of dissolved gas determinations before and after fermentation. They indicate a very great difference in quality between samples 3 and 4 on the one hand, and sample 5 on the other.

In sample 3, a slight fermentation took place on keeping, but it was practically confined to a nitrogen fermentation. In sample 4 the fermentation was more decided, and it consisted of a slight carbon as well as a slight nitrogen fermentation.

The analysis for sample 5 shows not only a very decided fermentation but also that it was also entirely confined to a carbon fermentation. As a matter of fact 0·28 parts of carbon per 100,000 of the water underwent fermentation, and ·033 parts of nitrogen were converted into ammonia during the process, but it is to be noted that about one-third of this nitrogen was derived from nitrates originally present, and only two-thirds from unfermented organic matter.

The analyses therefore show that the ratio of carbon to nitrogen in the unfermented organic matters originally present in the water was 1 : 10, a ratio which, taken together with the fact that the organic matters were unaccompanied by ammonia, proves them of vegetable origin, and that they were not derived from sewage. As a matter of fact I may explain that they were due to decaying vegetable matter of the autumn season.

The analytical details for samples 6 and 7 further illustrate the valuable and definite results obtainable by the aeration method. I need only refer to one point in connection with them. Sample 6 was collected on October 25th, when rain was commencing to fall after a somewhat lengthened period of fine dry weather, and at a time when rain had commenced to affect the water in upper reaches of the river.

Sample 7 was collected on the following day, after heavy rain had been falling for some hours previously. I mention these points to draw attention to the marked influence of the rain upon the quantity of carbon dioxide in the water at the commencement of the autumn season.

APPLICATION TO THE STUDY OF A POTABLE WATER-SUPPLY.

The next subject of examination which I wish to notice is that of the Rathmines water-supply, and I notice it in order to illustrate the value of a knowledge of the composition of the dissolved gases in certain cases of doubt in connection with potable waters.

The Rathmines water-supply is an upland surface-water of excellent quality, the catchment area being most carefully guarded against contamination of sewage matter of any kind.

In June and the early parts of July of last year, serious complaints were made by the residents of the Rathmines district, that the water as supplied to them was turbid and decidedly coloured, and often emitted unpleasant fish-oil odours, and even at times developed oily scums on its surface when drawn in large quantities for bath purposes, &c.

On investigation, the bad appearance and odour complained of were found to be due to unusually luxuriant growths of microscopic organisms of various kinds, but chiefly of Algæ and Diatoms. The water at the time was unfiltered, and consequently the consumers experienced to the full the effect of these luxurious growths immediately they began to die down and decay. The Waterworks comprise two reservoirs: the upper reservoir situated at Glan-na-Smol, Co. Dublin, and forming the storage tank, is 50 feet deep in the deepest part, and possesses a storage capacity of 350,000,000 gallons; and the lower or service reservoir, situated nearer Dublin, at Ballyboden, which has a storage capacity of 11,000,000 gallons.

The microscopic growths were particularly luxuriant in this latter reservoir, so much so, indeed, that the stones all round it, from the surface to a depth of 18 inches, were completely covered with a most luxuriant growth of filamentous Algæ.

The effect of the *débris* from the luxuriant vegetation is shown by the analyses recorded in Table II. Samples 2 and 3 were drawn from the lower service reservoir. The other samples represent the condition of the upper storage reservoir. On comparing the analyses recorded in the table, it is at once seen that the water from the upper reservoir, during its passage through the lower reservoir, received a marked addition of polluting matters; but I am more concerned at the present to draw attention to the value of a knowledge of the composition of the dissolved gases in the samples 5, 6, and 7 from the upper reservoir. These were all collected on the same day, namely July 24th, and represent the condition of the water in the reservoir at two different levels below its surface—samples 5 at about 5 feet below the surface, and samples 6 and 7 at about 20 feet below the surface. Sample 5 may be fairly taken to represent the average condition of the water as it entered the reservoir through the catch-water channels. Its analysis shows it to be slightly different in quality from the samples 6 and 7 from the 20-foot level. The analyses of the two latter samples indicate the existence of slight quantities of polluting matter at the lower depths of the reservoir; but with a knowledge of the composition of the dissolved gases in addition to the ordinary analytical data, we find that an active state of both carbon and nitrogen fermentation was taking place in the lower levels of the reservoir, and that the carbon fermentation was practically wholly due to vegetable *débris.*

The dissolved gases determinations also afford the necessary data for distinguishing the proportion of the dissolved oxygen consumed by the carbon fermentation from that consumed by the nitrogen fermentation in the manner I have described above.

TABLE II.—*Analyses of Samples of Water collected from the Rathmines Water Works at Glan-na-Smol, Co. Dublin.*

No.	Samples.*		Dissolved Gases expressed as volumes at N.T.P. per 1,000 vols. of water.				Other Constituents expressed as parts per 100,000 of the water.				
	Where Collected.	Description.	Carbon Dioxide.	Oxygen.	Oxygen† in per cent. of saturation.	Nitrogen.	Nitrogen as		Organic Nitrogen in		Total Solids.
							Ammonia.	Nitrates.	Suspension.	Solution.	
1	From the Lower Reservoir at Ballyboden, July 4, 1899, where supply enters.	Slightly turbid, yellowish green, faint indefinable odour - -	20·50	4·79	69·0	13·76	·0015	·025	·028	·01	9·2
2	From the Screen Chamber, just below Lower Reservoir, July 4.	Slightly turbid, peat brown tint, faint fish-oil odour - - -	21·28	4·71	68·5	13·71	·0023	·032	·031	·011	8·4
3	From the tap in Town Hall, July 4.	Decidedly turbid, peat brown tint, slight indefinable odour - -	21·27	3·96	59·2	13·37	·0005	·033	·021	·014	9·6
4	Ditto, July 5, supply drawn direct from upper Reservoir.	Very faintly turbid, yellowish green tint, odourless - - -	20·73	5·24	72·3	14·30	0·0	·028	·024	·015	9.2
5	From the Upper Reservoir, at Glan-na-Smol, 5 ft. below the surface, at the tower, July 24.	Very faintly turbid, yellowish green tint, odourless - - -	16·67	5·71	87·7	13·03	·007	·010	·012	·010	10·4
6	Ditto, about 20 ft. below the surface, July 24.	Faintly turbid, brown tint, slight indefinable odour - - -	19·54	2·00	30·23	13·23	·0035	·025	·026	·016	10·1
7	Ditto, July 24.	Ditto - - - - - - -	19·34	2·28	34·48	13·29	·0030	·026	·026	·016	10·0

* The bottles in which the samples were collected were completely filled and carefully stoppered, so as to leave no air in them, and their contents were preserved from contact with air until they were analysed. Samples 1, 2, 3, and 4 were kept for 29 days before the above analyses were made. The nitrogen as ammonia, and as organic (total), in proportions of the samples, when fresh, was ·01, ·012, ·007, ·008, and ·045, ·043, ·045, ·045, respectively.

Samples 5, 6, and 7 were kept 10 days before analysis.

† The figures in this column have been calculated upon the assumption that the volumes of oxygen required for saturation were equal to one-half those of the dissolved nitrogen.

NOTE.—None of the samples contained nitrites.

Dr. Adeney

APPLICATION TO THE STUDY OF THE WATERS OF A RIVER.

The third subject of study which I have to notice is the tidal portion of the river Liffey, or rather its estuary. Analyses of samples collected from both the surface and bottom waters of the estuary are recorded in Tables III. and IV. in the following pages.

After the references I have made to the two preceding tables it will be unnecessary to make any detailed reference to these further tables. I need only remark that the application of the aeration method to sea-water is attended with results quite as definite and as valuable as those obtainable when applied to the examination of fresh waters.

The "outfall" referred to in the tables is, I should explain, situated a few yards to the north of the South Wall, and about half a mile below the Pigeon House Harbour.

These analyses, besides illustrating the value of the aeration method when applied to the analysis of sea-waters, will be found, on careful examination, to afford some valuable evidence upon the question of the disposal of sewage matters from which the heavy solid matters have been previously separated by discharging them into tidal waters. It will be seen from the analyses that the effect of the liquid and the lighter solid sewage matters discharged from so populous a city as Dublin and its neighbouring districts is confined in calm weather to the surface waters of the estuary, the bottom waters being but slightly affected even at low tides. Thus in samples 9 and 10, Table IV., the percentage of oxygen found in a sample of the surface water, collected at low spring tide opposite the Pigeon House Harbour, and in calm weather, was 9·9, after it had been kept for five days out of contact with air, while the percentage of oxygen found in the sample collected at the same spot, but 14 feet below the surface, was 86·37.

TABLE III.

Analyses of Samples of Estuary Water collected during the last two hours of the Ebb (Neap Tide), March 9th, 1900.

(High-water at 4·55 a.m. Weather very dry and calm; no rain for the previous seven days, with light E. and N.E. winds. Temperature of water at surface, 8° C.)

No.	SURFACE AND BOTTOM SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
			Carbon Dioxide.	Oxygen.	Oxygen in per cent. of Saturation.*	Nitrogen.	Nitrogen as			Chlorine	Solids in Solution.	Solids in Suspension.	
							Ammonia.	Nitrates.	Organic.			Inorganic.	Organic.
	Sewage from Penstock - -	3 hours.	113·73	3·83	0·00	16·75	·300	·750	·130	191	446	1·135	3·365
1	Over Outfall† at 9.5 a.m. - -	4 „	85·05	5·27	68·84	15·31	·160	·340	·060	837	1651	1·285	0·715
2	10 yds. below Outfall in path of sewage, and 2 ft. below surface, at 9.9 a.m. - - -	5 „	53·73	6·24	89·76	13·90	·004	·051	·086	1575	3057	Traces.	
3	Ditto, at surface, at 9.12 a.m. -	6 „	63·20	5·95	82·22	14·47	·042	·158	·088	1295	2527	Traces.	
4	50 yds. below Outfall, and 2 ft. below surface, at 9.14 a.m. in path of sewage - - -	30 „	54·27	6·15	86·74	14·17	·015	·013	·045	1554	3066	Traces.	
5	Ditto, at surface, at 9.17 a.m. -	31 „	60·96	5·77	79·72	14·48	·042	·083	·010	1313	2565	Traces.	
6	100 yds. below Outfall, and 4 ft. below surface, in path of sewage, at 9.19 a.m. - -	7 days.	52·97	5·35	76·32	14·02	·012	·028	·042	1617	3135	Traces.	
7	Ditto, at surface, at 9.22 a.m. -	7 „	61·27	4·80	67·32	14·26	·032	·086	·038	1348	2614	Traces.	

---

* The figures in this column and in the similar column of the succeeding Table have been calculated on the basis that the volume of oxygen required for saturation was equal to half the volume of the nitrogen in them.

† The Rathmines and Pembroke Outfall Works.—Sample 2 was collected perpendicularly over the Outfall when it was covered by 2 feet of water.

TABLE III.—*Analyses of Samples of Estuary Water collected during the last two hours of the Ebb (Neap Tide), March 9th*, 1900—continued.

No.	SURFACE AND BOTTOM SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
							Nitrogen as					Solids in suspension.	
			Carbon Dioxide.	Oxygen.	Oxygen in per cent. of Saturation.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solids in solution.	Inorganic.	Organic.
8	Mid-way between Outfall and mouth of Harbour, near the S. Wall, 7 ft. below the surface at 9·30 a.m. - - - -	10 days	50·47	6·11	87·54	13·96	·006	·016	·054	1663	3280	Traces.	
9	Ditto at surface, at 9·32 a.m. -	10 „	59·27	4·37	61·29	14·26	·015	·035	·064	1400	2711	Traces.	
10	Mid-way between outfall and mouth of Harbour, and a little to N. of path of sewage, 7ft. below the surface, at 9.34 a.m. - - - - -	10 „	50·27	5·79	83·43	13·88	·001	·012	·036	1694	3295	Traces.	
11	Ditto at surface, at 9·37 a.m. -	10 „	56·93	4·83	67·41	14·30	·004	028	·058	1400	2742	Traces.	
12	In deep channel near Lightbuoy 1, 21 ft. below the surface, at 9.40 a.m. - - - -	11 „	48·97	6·49	92·45	14·04	·007	·014	·016	1768	3457	Traces.	
13	Ditto at surface, at 9.53 a.m. -	11 „	57·85	4·77	67·56	14·13	·016	·031	·040	1335	2670	Traces.	
14	100 yds. above Outfall mid-way between S. Wall and deep-water channel, 7 ft. below the surface, at 10.10 a.m. - -	11 „	55·12	5·11	72·69	14·07	·017	·026	·038	1523	2904	Traces.	
15	Ditto at the surface, at 10.13 a.m. - - - - -	11 „	65·51	3·16	43·23	14·62	·034	·055	·048	1155	2742	Traces.	

---

* The figures in this column and in the similar column of the succeeding Table have been calculated on the basis that the volume of oxygen required for saturation was equal to half the volume of the nitrogen in them.

TABLE IV.

Analyses of Samples of Estuary Water collected during the last two hours of the Ebb (Spring Tide) March 2nd, 1900.

(Weather fine, no rain during the preceding forty-eight hours; light N.-W, winds. High tide, 11.32 a.m. Temperature of water at surface, 10° C.)

No.	SURFACE AND BOTTOM SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
							Nitrogen as					Solids in suspension.	
			Carbon Dioxide.	Oxygen.	Oxygen in per cent. of saturation.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solids in Solution.	Mineral.	Organic.
	Sewage from Penstock chamber. Very turbid - - - -	23 hrs.	129·80	0·00	0·00	18·50	1·13	·82	·270	172	414	4·47	9·93
16	Over Outfall,† at 4.5 p.m. Turbid; odourless - - - -	19 ,,	125·80	1·01	11·69	17·25	1·00	·80	·150	210	486	3·97	6·03
17	100 yards above Outfall, near Buoy 2, in mid-channel, 15 feet below surface, 4.10 p.m. Clear; odourless - - -	4 days.	51·41	6·60	91·92	14·35	·000	·024	·062	1631	3169	5·14	1·265
18	Ditto, at the surface. Distinctly turbid; odourless - - -	4 ,,	62·07	4·70	60·72	15·48	·003	·065	·071	921	1829	Traces.	
19	100 yards below Outfall, near the S. Wall, at 4·20 p.m., in shallow water. Turbid; odourless - - - -	20 hrs.	69·41	5·21	69·34	15·03	·080	·420	·170	980	1906	2·47	1·73

Solids in Suspension.—The solids in the bottom water samples were of a light granular character; those in the surface water samples were of a very fine granular character, with occasional pieces of light flocculent matter.

* See footnote 1, Table III.

† See footnote 2, Table III.

TABLE IV.—*Analyses of Samples of Estuary Water collected during the last two hours of the Ebb (Spring Tide), March 2nd*, 1900—continued.

No.	SURFACE AND BOTTOM SAMPLES. Where collected; description.	Time kept.	Gaseous constituents expressed as volumes at N.T.P. per 1,000 volumes of water.				Other constituents as parts by weight per 100,000 parts of water.						
							Nitrogen as					Solids in Suspension.	
			Carbon Dioxide.	Oxygen.	Oxygen in per cent. of Saturation.*	Nitrogen.	Ammonia.	Nitrates.	Organic.	Chlorine.	Solids in Solution.	Mineral.	Organic.
20	Below Outfall, midway between the S. Wall and the Light-buoy 1, 14 in. below surface, at 4·28 p.m. Turbid; odourless -	3 days.	55·12	5·73	76·60	14·96	·003	·088	·037	1267	2484	1·28	0·32
21	Ditto, at surface, at 4.30 p.m. Turbid; odourless - - -	3 "	56·53	5.19	70·04	14·83	·004	·056	·060	1250	2411	0·63	0·00
22	Mid-channel, near Light-buoy 1, 14 feet below the surface, at 4.35 p.m. Clear; odourless -	4 "	51·03	6·67	93·29	14·30	·002	·024	·034	1503	3151	2·885	2·215
23	Ditto at surface, 4.37 p.m. Slightly turbid; odourless -	4 "	55·96	5·98	89·59	14·84	·004	·026	·034	1330	2602	Traces.	
24	Above Outfall, mid-channel, opposite Pigeon House Harbour, 14 feet below surface, at 5.22 p.m. Faintly turbid; odourless - - - - -	5 "	51·34	6·18	86·37	14·31	·018	·007	·036	1579	3098	3·885	1·715
25	Ditto, at surface, at 5.26 p.m. Turbid; odourless - - -	5 "	72·61	0·82	9·90	16·48	·120	·070	·130	459	929	Traces.	

Solids in Suspension.—The solids in the bottom water samples were of a light granular character; those in the surface water samples were of a very fine granular character, with occasional pieces of light flocculent matter.

* See footnote 1, Table III.

ERRORS ARISING WHEN THE OXYGEN ONLY OF THE DISSOLVED GASES IS DETERMINED.

One further point which these analyses illustrate, and which must be here emphasized, is the nature and extent of the error to which I referred in the earlier part of this paper as more or less seriously affecting the results obtained by volumetric methods for dissolved oxygen.

The practice hitherto amongst analysts for the estimation of the dissolved oxygen in a water, when such has been necessary, has been to adopt one of the volumetric methods, and to employ, for the purpose of calculating the quantities of oxygen found into percentages of saturation, tables giving the maximum quantities of oxygen which distilled water holds in solution when saturated, at different temperatures.

Although it is well known that accurate determinations of the actual quantity of oxygen dissolved in the water may be made, within certain limiting conditions, by Schutzenberger's, or by Thresh's, volumetric method, a serious difficulty arises when it comes to the question of the standard of oxygen saturation to be taken for the purpose of calculation. This becomes evident immediately it is remembered that the composition of the dissolved gases in still water alters very slowly with alterations of temperature, so that samples of a good fresh river water may be, and probably always are, either over-saturated or under-saturated with oxygen for the temperatures of the water at the times of collection.

When it happens that the waters examined are pure sea water, or mixtures of sea and river waters, such as in tidal rivers, the error becomes still more serious, since the solubility of atmospheric oxygen is very much less in sea water than in fresh, temperature for temperature.

If, however, the dissolved nitrogen, as well as the oxygen, be determined, we have thereby the means of calculating whether the volume of dissolved oxygen found does actually represent the state of oxygen saturated for the conditions to which the water had been subjected at the time it was collected, or of calculating, if it does not, its exact amount below that state.

The truth of these statements will be apparent from the following table, showing the solubility of atmospheric nitrogen and oxygen at different temperatures in distilled and in sea waters :—

The gases are expressed in c.cs., at N.T.P., per 1,000 c.cs. of water.

Temperature.	Sea-water.*		Distilled water.†		Sea-water.	Distilled water.
	Nitrogen.	Oxygen.	Nitrogen.	Oxygen.		
10° C.	12·47	6·45	15·47	7·87	$O_2 = \frac{N_2}{1{\cdot}933}$	$\frac{N_2}{1{\cdot}966}$
15° C.	11·34	5·83	13·83	7·09	$O_2 = \frac{N_2}{1{\cdot}945}$	$\frac{N_2}{1{\cdot}951}$
20° C.	10·41	5·31	12·76	6·53	$O_2 = \frac{N_2}{1{\cdot}960}$	$\frac{N_2}{1{\cdot}954}$
25° C.	9·62	4·87	11·81	5·97	$O_2 = \frac{N_2}{1{\cdot}975}$	$\frac{N_2}{1{\cdot}978}$

* Dittmar, "Challenger" Reports, p. 224.

† Roscoe and Lunt, Journ. Chem. Soc., 1889, 552.

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APPENDIX VIII.

MANURIAL VALUE OF SEWAGE SLUDGE.

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ROYAL COMMISSION ON SEWAGE DISPOSAL.

I. EXPERIMENTS WITH SEWAGE SLUDGES ON MANGOLDS AND TURNIPS IN 1905–6.

In the spring of 1905 the Board of Agriculture were approached by the Royal Commission on Sewage Disposal, with the view of assisting them to obtain facilities at one or more collegiate centres or experimental stations, for testing under practical agricultural conditions certain dessicated sewage products commonly called "sludges." The Board consequently entered into provisional arrangements with the following colleges and stations:—

Rothamsted Experimental Station (through Mr. A. D. Hall).
Cambridge University Department of Agriculture (through Professor Middleton).
Leeds University Department of Agriculture (through Professor Seton).
S. E. Agricultural College, Wye (through Professor M. J. R. Dunstan).
Glasgow and West of Scotland College of Agriculture (through Professor Wright).

The land on which the experiments were carried out was of the following character:—

At Rothamsted, strong flinty loam overlying Chalk.
At Cambridge, moderate gritty loam overlying Gault.
At Leeds, strong drift soil overlying the Coal Measures.
At Wye, strong flinty loam overlying Chalk.
At Glasgow, strong loam on the Carboniferous Formation.

It was arranged that the tests should be made on roots (turnips, swedes or mangolds), that each plot should, if possible, be one-twentieth of an acre in extent, and that all the plots should be duplicated.

Seven sludges were selected for experiment, and consignments were delivered to the various centres under a number, the origin and character of the materials not being divulged. The preparation of those sludges and their chemical and bacteriological analyses are given on pp. 8–11.

The material was put up in bags of 1 cwt. each, but on May 1st Professor Middleton wrote to say that many of the bags on arrival weighed less than 100 lbs., the loss of weight being doubtless due to evaporation of water on the journey. As no manurial constituent could have disappeared, Professor Middleton and the other experimenters were asked to weigh all the seven consignments, and from the results to re-calculate the quantities given in the accompanying Table (No. 1). The amounts of Phosphoric Acid and Nitrogen shown in the Table were actually applied to the plots concerned (except in the case of Cambridge, where the actual quantities of sludge specified in the Table were used), though the figures are based on the weights of the sludges as put on rail.

The artificial manures used in the experiment were analysed at the various centres with the following percentage results:—

——	Leeds.	Glasgow.	Rothamsted.	Cambridge.	Wye.
Sulphate of Ammonia	N = 20·28	N = 20·20	N = 19·8	N = 20·3	N = 19·76
Superphosphate - -	Sol. P_2O_5 = 12·04 Insol. ,, = 0·57	Sol. P_2O_5 = 13·19	Sol. P_2O_5 = 17·5	Sol. P_2O_5 = 14·8	Sol. P_2O_5 = 11·91
Potash Salt - - -	K_2O = 57·84	K_2O = 32·35	K_2O = 49·5	K_2O = 51.8	K_2O = 43·26
Fish Meal - - -	N = 8·75 P_2O_5 = 8·81	N = 7·24 P_2O_5 = 6·76	N = 7·78 P_2O_5 = 6·87	N = 8·30 P_2O_5 = 6·26	N = 8·32 P_2O_5 = 7·42

The mangold seed was sown early in May, and the turnip and swede seed somewhat later.

On October 20th Sir Wm. Ramsay suggested that an analysis should be made of samples of the roots from certain of the plots, and the experimenters were asked to determine the sugar, nitrogen and water in samples of roots grown on Plots 5A, 6A, 7A and 19A. The crop, however, proved to have been lifted at that date at some of the centres, so that these analyses were only made on the crops grown at Cambridge and Wye. At Cambridge a mistake was made in not taking samples from the roots of Plot 19A, so that analytical figures for that plot from this centre are not available.

The scheme of the experiment was as follows:—

Plots	1A	and	1B.	2072 lbs.	Sludge No. 7.
,,	2A	,,	2B.	2072 ,,	,, No. 6.
,,	3A	,,	3B.	2072 ,,	,, No. 5.
,,	4A	,,	4B.	2072 ,,	,, No. 4.
,,	5A	,,	5B.	2072 ,,	,, No. 3.
,,	6A	,,	6B.	2072 ,,	,, No. 2.
,,	7A	,,	7B.	2072 ,,	,, No. 1 (contains 40 lbs. N. and 36 lbs. P_2O_5).
,,	8A	,,	8B.	1036 ,,	,, No. 1.
,,	9A	,,	9B.	No manure.	
,,	10A	,,	10B.	3108 lbs.	,, No. 1.
,,	11A	,,	11B.	2072 ,,	,, No. 1, plus 20 lbs. N. in Sulphate of Ammonia.
,,	12A	,,	12B.	2072 ,,	,, No. 1, plus 18 lbs. Sol. Phos. Acid in superphosphate.
,,	13A	,,	13B.	2072 ,,	,, No. 1, plus 20 lbs. N. in Sul. Am. and 18 lbs. Phos. Acid in superphosphate.
,,	14A	,,	14B.	No sludge.	Super supplying 18 lbs. Phos. Acid.
,,	15A	,,	15B.	,, ,,	,, ,, 36 lbs. ,, ,,
,,	16A	,,	16B.	,, ,,	Sul. Am. ,, 20 lbs. N.
,,	17A	,,	17B.	,, ,,	,, ,, ,, 40 lbs. N.
,,	18A	,,	18B.	,, ,,	,, ,, ,, 20 lbs. N. plus 36 lbs. Phos. Acid in superphosphate.
,,	19A	,,	19B.	,, ,,	,, ,, ,, 40 lbs. N. plus 36 lbs. ,, ,, ,,
,,	20A	,,	20B.	,, ,,	,, ,, ,, 40 lbs. N. plus 18 lbs. ,, ,, ,,
,,	21A	,,	21B.	,, ,,	,, ,, ,, 20 lbs. N. plus 18 lbs. ,, ,, ,,
,,	22A	,,	22B.	,, ,,	Fish Meal supplying 40 lbs. N. (Phos. Acid indefinite).

In order to counteract any slight effect from the small amount of potash present in the sludges, the whole experimental area received an equal dressing of a potash salt, supplying 30 lbs. potash per acre. In discussing results therefore, this substance will be neglected. It is well that this precaution was taken, as is evident from the result obtained on an extra plot at Rothamsted which received at the rate of 4,144 lb. per acre of No. 1 Sludge, but no potash. The crop on this plot, in duplicate, averaged less than 16 tons per acre, as compared with over 20 tons on the plot receiving potash alone. Plots 9A and 9B were left unmanured, except for the potash. A typical sludge (No. 1), prepared by the "A.B.C." process, was selected as the basis of comparison, and, its analytical composition being known, 2,072 lbs. were applied per acre to Plots 7A and 7B, supplying 40 lbs. nitrogen, and 36 lbs. phosphoric acid. The same aggregate weight of the other sludges was used on Plots 1A to 6A, with their duplicates 1B to 6B, but as their chemical composition necessarily differed from that of Sludge No. 1, the nitrogen and phosphoric acid did not actually agree with the figures just given (*see* Table 1).

Plots 8A and 10A, with their duplicates, received respectively 50 per cent. less and 50 per cent. more sludge (No. 1) than was used on Plot 7A and its duplicate.

Plots 11A and 11B received the same amount and kind of sludge as 7A and 7B, but with the addition of 20 lbs. nitrogen as sulphate of ammonia.

Plots 12A and 12B were treated like 7A and 7B, but with the addition of 18 lbs. of soluble phosphoric acid in superphosphate.

Plots 13A and 13B received the sludge of 7A and 7B, but with the addition of both 20 lbs. of nitrogen in sulphate of ammonia, and of 18 lbs. of phosphoric acid in superphosphate.

The other plots of the series received no sludge, but only standard artificial manures in varying quantity, the object being to ascertain how the latter would influence the crop as compared with the sludges.

The season was somewhat abnormal in character and, on the whole, not very favourable to the action of manures. From the Midlands northwards, the early part of the summer was characterised by great deficiency of rain and a high temperature, with the result that seed germinated badly and young plants experienced a check in growth. At Leeds the root-crop on the experimental area was a complete failure, so that no figures are available from that centre. At the other centres the yields are fair, being above the average at Cambridge, and below the average at Glasgow.

Before examining the results due to the sludges, it may be well to look at those obtained with standard artificial manures, superphosphate, sulphate of ammonia and fish meal. In this way we determined the sensitiveness of the soil to manurial treatment, and obtained a reliable basis for comparing the action of sludges with artificial manures.

Effect of Nitrogen derived from Sulphate of Ammonia.

Plots 9, 16 and 17 show the effect of sulphate of ammonia used alone in quantities sufficient to supply 20 and 40 lbs. of nitrogen respectively per acre. Used on turnips and swedes in Scotland and Kent, this treatment has produced no positive result, in fact the yield is invariably reduced both when the smaller and larger dressing of nitrogen is employed. This confirms the belief that is generally held that nitrogen alone, unsupported by phosphates, has little effect on turnips and swedes.

On mangolds, as will be seen from the Rothamsted and Cambridge figures, a large increase has been produced by both dressings of nitrogen. At Rothamsted the yield is raised 6 tons and 5 tons per acre by the smaller dressing (compare Plots 9 and 16 with duplicates), while a further increase of some 2 tons is secured by doubling the nitrogen. At Cambridge the results are not so consistent, but on the whole nitrogen has improved the crop.

It is important in this connection to compare Plots 21 and 20 with Plots 7 and 11. Numbers 7 and 21 received their N and P_2O_5 from: (*a*) Sludge No. 1, and (*b*) superphosphate and sulphate of ammonia, respectively. To each was added 20 lbs. of N derived from sulphate of ammonia (Plots 11 and 20 respectively), with the result that only at Glasgow had the ammonia any effect when added to superphosphate and sulphate of ammonia, whereas when added to sludge it produced marked and consistent effects at Glasgow, Rothamsted and Cambridge, and on the "B" plots at Wye. The conclusion to be drawn is that the N in the sludge was so inactive that further additions as sulphate of ammonia had the opportunity to exert their influence.

Next we may look at the effects of using 20 and 40 lbs. of nitrogen derived from sulphate of ammonia on land already dressed with 18 lbs. of soluble phosphoric acid derived from superphosphate. The figures that deal with this point are yielded by Plots 14, 21, 20, in the order given. In every case, with mangolds, turnips and swedes, the use of 20 lbs. of nitrogen in the presence of phosphate has produced a marked increase in yield, averaging 3½ tons at Glasgow (turnips), nearly 2 tons at Wye (swedes), 2 tons at Cambridge (mangolds), and practically 13 tons at Rothamsted (mangolds). The effect of doubling the nitrogen in the form of sulphate of ammonia in the presence of superphosphate has been rather remarkable (compare Plots 21 and 20), for, with only the single exception of Glasgow, the crop has been larger with the small, than with the big dose of nitrogen.

Further, by comparing Plots 15, 18, 19, in the order named, we see what 20 and 40 lbs. of nitrogen respectively can do, in the presence of 36 lbs. of P_2O_5 derived from superphosphate. Except at Cambridge the smaller quantity of N has always produced an increase, which averaged 1½ tons at Glasgow (turnips), 1 ton at Wye (swedes), and 4 tons at Rothamsted (mangolds). At Cambridge the yield was reduced on an average by fully a ton per acre. The further use of 20 lbs. N (compare Plots 18 and 19) has produced increases at three of the centres, averaging about 1½ tons at Glasgow (turnips), nearly 1 ton at Rothamsted (mangolds), and fully 1½ tons at Cambridge (mangolds). At Wye (swedes), on the other hand, the average crop was not improved by doubling the nitrogen in the presence of 36 lbs. of P_2O_5.

Effect of Phosphoric Acid derived from Superphosphate.

Next, we may look at the analogous effects of soluble phosphoric acid derived from superphosphate, and first we will take the respective effects of 18 and 36 lbs. per acre used alone, that is to say in the absence of any concurrent manuring. The plots that deal with this point are 9, 14, and 15, in the order named. At Glasgow, Wye and Rothamsted the crop is invariably lower when 18 lbs. of P_2O_5 were used than on the unmanured plot, and the same is true of the "B" plots at Cambridge. But except at Wye an invariable increase is secured by doubling the P_2O_5, and at each of these centres the yield is larger when 36 lbs. of P_2O_5 are employed than where the plot is altogether untreated.

We have also the opportunity on Plots 16, 21 and 18 of comparing the effects of adding 18 and 36 lbs. of P_2O to 20 lbs. of N derived from sulphate of ammonia. At Glasgow (turnips) increasing doses of P_2O_5 have produced increasing yields of roots, the rise on the average of the two sets of plots being from 13¼ tons (Plot 16) to 16¾ tons (Plot 21) to 17¾ tons (Plot 18). At all the other stations the smaller dose of phosphate has produced an increase that is never less than a ton, and at Rothamsted was 5½ tons. But at these stations the larger dressing of superphosphate has produced a markedly lower yield than the smaller dressing, and this result is uniformly confirmed by the duplicate plots. The important point, however, is that at each of the four stations, and without exception on the duplicate plots as well, the smaller dressing of superphosphate (18 lbs. P_2O_5) has in the presence of 20 lbs. of N uniformly produced an increase, which on the average of the eight plots, has amounted to over three tons per acre.

If we compare Plots 7 and 12 with Plots 21 and 18, we shall see the effect 18 lbs. of soluble P_2O_5 when added to: (*a*) Sludge No. 1., and (*b*) superphosphate and sulphate of ammonia, respectively. We find that the 18 lbs. of P_2O_5 has produced increases when added to sludge five times in eight, whereas when added to superphosphate and sulphate of ammonia it has produced increases only two times in eight, and both of these increases occurred at Glasgow. From this we should conclude that the phosphate in the sludge is less active than the phosphate in the superphosphate, because the addition of a further supply of P_2O_5 produces more effect in the former case than in the latter.

So far the evidence goes to show that the nitrogen in Sludge No. 1 is not so active as the nitrogen of sulphate of ammonia, neither is the P_2O_5 of Sludge No. 1 so active as the P_2O_5 of superphosphate. A further opportunity occurs to test the conjoint action of 20 lbs. N and 18 lbs. P_2O_5 derived from sulphate of ammonia and superphosphate, when used in the presence of: (*a*) Sludge No. 1, and (*b*) sulphate of ammonia and superphosphate. To do so we compare Plots 7 with 13 and 21 with 19. The evidence is not very strong, but such as it is, it goes to confirm what we have already found. When the N and P_2O_5 are added to sludge, an increase (aggregating 18 tons) was obtained six times in eight, while on the seventh occasion there was neither an increase nor a decrease. When these substances were added to sulphate of ammonia and superphosphate, an increase (aggregating 5 tons) was got only four times in eight.

Comparative effects of Nitrogen and Phosphoric Acid derived from Sludge and from Sulphate of Ammonia and Superphosphate.

We may now proceed directly to compare the effects of equal quantities of N (20 lbs.) and P_2O_5 (18 lbs.), derived from No. 1 Sludge (Plot 8) and from sulphate of ammonia and superphosphate (Plot 21). Without any exception in the eight tests—that is to say, on the four duplicate plots at each station—the sludge has proved distinctly, and generally markedly, inferior to the other dressing. In point of fact the crop grown with the sludge was, on the average of all the stations, actually 9 cwt. per acre less on Plot 8 (1,036 lbs. No. 1 Sludge) than on Plot 9 (unmanured), whereas on Plot 21 (receiving the same amount of P_2O_5 and N, but derived from superphosphate and sulphate of ammonia), the average increase of crop was more than 4½ tons per acre.

Again, we may examine the same point on Plots 7 and 19, where equal quantities of N (40 lbs) and P_2O_5 (36 lbs.) were used, derived respectively from No. 1 Sludge and sulphate of ammonia plus superphosphate. Here we find that, except at Wye, the sludge-grown crop is markedly inferior to that grown with sulphate of ammonia and superphosphate.

Comparative effects of Sludge and Fish Meal.

We may also compare the results with an equal quantity of N and a practically equal quantity of P_2O_5 derived from fish meal (Plot 22), and here the evidence is overwhelmingly in favour of the fish meal as compared with the sludge.

These comparisons were all made with Sludge No. 1, which was regarded as a typical material and already on the market as an article of commerce. Before turning to look at the action of the other sludges, we may exhaust the comparative tests that were made with Sludge No. 1. Examination of Plots 8, 7, 10, in the order named, will show that this sludge was used in three quantities supplying: (*a*) 20 lbs. N and 18 lbs. P_2O_5, (*b*) 40 lbs. N and 36 lbs. P_2O_5, and (*c*) 60 lbs. N and 54 lbs. P_2O_5 respectively per acre. At Glasgow, Wye and Cambridge there is no distinct evidence that the sludge has produced any effect, that is to say, the crop on the unmanured land is practically as good as that on the plots getting varying amounts of a sludge, but at Rothamsted it appears to have been more effective, though even there very much less so than a mixture of superphosphate and sulphate of ammonia, such, for instance, as was applied to Plot 19.

The relative effects of the various Sludges.

When we compare the action of the seven sludges used at the rate of 2,072 lbs. per acre, we can trace no consistent superiority or inferiority in any of them. All the variations that are met with are well within the limits of experimental error. Taking the average of all the centres, and the average of the seven plots that got 2,072 lbs. of sludge, we find that the yield works out at 19 tons 7 cwt. per acre, which is practically ½ ton less than the average yield on the unmanured Plot (No. 9). Or, looked at from another point of view, it will be seen that the highest average yield of any of the sludges is that of No. 2 on Plot 6, where it amounts to 20 tons 5¾ cwts., a figure that is lower than the average yield on any of the plots receiving artificial manure.

Quality of the crop.

The percentage composition of the roots, as determined on carefully selected samples, is set forth in Table II. In the case of the three sludges tried on the plots whose produce was sampled, the analytical figures supplied by the two centres are very consistent. The nitrogen is uniformly lowest on Plot 5 (No. 3 Sludge) and highest on Plot 7 (No. 1 Sludge). The sludge of the latter plot supplied most nitrogen, and this apparently is reflected in the composition of the crop.

As regards the sugar, this is uniformly highest in the roots grown on Plot 6 (No. 2 Sludge), and lowest in those yielded by Plot 7 (No. 1 Sludge). At both stations, therefore, the nitrogen and sugar are in inverse ratio, a result that is consistent with expectation. As sugar is generally regarded as the best index of quality in mangolds and swedes, the results would indicate that, of the three Sludges, No. 2 (which is lowest both in nitrogen and phosphoric acid, but highest in lime) most favourably influenced the crop.

The crop on Plot 19 was inadvertently not sampled at Cambridge, but at Wye it will be seen that, using equal quantities of N and P_2O_5 derived respectively from No. 1 sludge (Plot 7) and from sulphate of ammonia and superphosphate (Plot 19), the dry matter and sugar of the roots are lower under the influence of the sludge than is the case with the sulphate of ammonia and superphosphate, whereas the reverse is the case with the dry matter.

General Conclusion.

So far as these experiments go, they show that in the season of 1905 none of the sludges experimented with produced any consistent manurial effect on the growth of turnips, swedes or mangolds. Although the season was not a good one for the growth of the root crop, it permitted artificial manures to exert considerable influence on the yield of this crop. We would therefore appear to be justified in drawing the conclusion that the nitrogen and phosphoric acid of sludge are in a much less available form than the same substances in sulphate of ammonia, superphosphate and fish meal.

TABLE I. RESULTS OF SEWAGE SLUDGE EXPERIMENTS WITH ROOTS AT FOUR CENTRES, 1905.

Plot.	Manures per acre.					Yield. The Glasgow and West of Scotland Agricultural College. (Turnips.)			Yield. The Rothamsted Experimental Station. (Mangolds.)			Yield. The South Eastern Agriculture College, Wye. (Swedes.)			Yield. The Agricultural Department, Cambridge University. (Mangolds.)			General Average Yield.	Plot.
	Sewage Sludge.		Sul. of Amm.	Super-phosphate.	Fish Meal.	Plot A.	Plot B.	Avge.	Plot A.	Plot B.	Avge.	Plot A.	Plot B.	Avge.	Plot A.	Plot B.	Avge.		
	No.	Amount per acre.																	
		lbs. lbs.	lbs. N.	lbs. Sol. P_2O_5.	lbs. N.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	T. C.	
1	7	2072 $\begin{Bmatrix} N = 27 \\ P_2O_5 = 23 \end{Bmatrix}$	–	–	–	11 0	12 0	11 10	20 5	20 15	20 10	13 10	15 4½	14 7¼	30 0	30 16¼	30 8	19 3¾	1
2	6	2072 $\begin{Bmatrix} N = 30 \\ P_2O_5 = 17 \end{Bmatrix}$	–	–	–	10 15	11 0	10 17½	17 10	19 2½	18 6¼	15 11½	15 18½	15 15	30 8¾	30 13¾	30 10¾	18 17½	2
3	5	2072 $\begin{Bmatrix} N = 29 \\ P_2O_5 = 14 \end{Bmatrix}$	–	–	–	10 15	10 0	10 7½	21 12½	23 2½	22 7½	15 18¼	14 11¼	15 4¾	32 17½	29 8¾	31 3	19 15	3
4	4	2072 $\begin{Bmatrix} N = 22 \\ P_2O_5 = 44 \end{Bmatrix}$	–	–	–	12 0	11 10	11 15	18 17½	20 2½	19 10	16 5¼	14 10½	15 7¾	31 7½	31 8¾	31 7¾	19 10	4
5	3	2072 $\begin{Bmatrix} N = 26 \\ P_2O_5 = 20 \end{Bmatrix}$	–	–	–	12 10	11 10	12 0	17 2½	18 2½	17 12½	15 17½	14 2¾	15 0¼	30 17½	30 5	30 11¼	18 16	5
6	2	2072 $\begin{Bmatrix} N = 18 \\ P_2O_5 = 14 \end{Bmatrix}$	–	–	–	13 0	13 10	13 5	19 0	20 7½	19 13¾	16 14¼	14 11¾	15 13	33 15	31 6¼	32 10¾	20 5¾	6
7	1	2072 $\begin{Bmatrix} N = 40 \\ P_2O_5 = 36 \end{Bmatrix}$	–	–	–	10 10	9 10	10 0	19 7½	23 2½	21 5	16 11	14 11¾	15 11½	28 11¼	30 18¾	29 15	19 2¾	7
8	1	1036 $\begin{Bmatrix} N = 20 \\ P_2O_5 = 18 \end{Bmatrix}$	...	–	–	11 10	11 0	11 5	19 15	20 15	20 5	15 17¼	14 9¾	15 3½	30 15	31 0	30 17½	19 7¾	8
9		Unmanured.	–	–	–	14 0	14 10	14 5	18 17½	21 10	20 3¾	14 17¼	14 16½	14 16¾	28 15	31 7½	30 1¼	19 16¾	9
10	1	3108 $\begin{Bmatrix} N = 60 \\ P_2O_5 = 54 \end{Bmatrix}$	–	–	–	10 10	10 10	10 10	25 2½	27 15	26 8¾	14 19	16 1¾	15 10½	29 2½	31 17½	30 10	20 14¾	10
11	1	2072 $\begin{Bmatrix} N = 40 \\ P_2O_5 = 36 \end{Bmatrix}$	20	–	–	12 10	11 10	12 0	24 0	25 5	24 12½	15 16½	15 1	15 8¾	31 12½	32 12½	32 2½	21 1	11
12	1	2072 $\begin{Bmatrix} N = 40 \\ P_2O_5 = 36 \end{Bmatrix}$	–	18	–	14 5	16 0	15 2½	19 17½	22 5	21 1¼	15 13½	15 17	15 15¼	32 16¼	29 15	31 5½	20 16	12
13	1	2072 $\begin{Bmatrix} N = 40 \\ P_2O_5 = 36 \end{Bmatrix}$	20	18	–	15 0	15 10	15 5	22 0	23 2½	22 11¼	14 7¾	15 0¼	14 14	31 15	32 5	32 0	21 2½	13
14	–	No Sludge.	–	18	–	13 10	14 0	13 15	18 5	18 5	18 5	14 11¾	14 2	14 6¾	33 8¾	30 8¾	31 18¾	20 11¼	14
15	–	No Sludge.	–	36	–	16 0	16 10	16 5	22 12½	23 7½	23 0	13 18	14 1½	13 19¾	33 18¾	31 12½	32 15¾	21 10	15
16	–	No Sludge.	20	–	–	13 0	13 10	13 5	24 17½	26 10	25 13¾	13 16	14 16	14 6	33 6¼	31 2½	32 4¼	21 7¼	16
17	–	No Sludge.	40	–	–	13 0	13 10	13 5	26 15	28 7½	27 11¼	13 0	14 12¼	13 16	33 1¼	31 16¼	32 8¾	21 15¼	17
18	–	No Sludge.	20	36	–	17 0	18 10	17 15	26 7½	27 12½	27 0	15 7¾	14 11¾	14 19½	33 7½	29 11¼	31 9¼	22 16	18
19	–	No Sludge.	40	36	–	19 15	18 10	19 2½	27 0	28 17½	27 18¾	16 4¼	13 3	14 13¾	32 8¾	33 16¼	33 2½	23 14¼	19
20	–	No Sludge.	40	18	–	18 15	18 5	18 10	28 5	31 0	29 12½	15 10	15 8¼	15 9	33 2½	31 7½	32 5	23 19¼	20
21	–	No Sludge.	20	18	–	16 0	17 10	16 15	30 7½	32 0	31 3¾	16 0½	16 2	16 1¼	34 17½	32 18¾	33 18	24 9½	21
22	–	No Sludge.	–	–	40	19 0	20 0	19 10	33 2½	33 10	33 6¼	16 9½	16 10	16 9¾	34 11¼	33 18¾	34 5	25 17¾	22

Table II.

Percentage Composition of the Roots grown on selected Plots at Cambridge (Mangolds) and Wye (Swedes).

Plot.	Manure per Acre.	Dry Matter.		Sugar.		N in dry matter.	
		Camb.	Wye.	Camb.	Wye.	Camb.	Wye.
5 A	26 lbs. N and 20 lbs. P_2O_5 in Sludge No. 3	14·1	11·80	9·2	4·27	·150	1·70
6 A	18 „ „ and 14 „ „ „ „ 2	13·9	11·43	9·3	5·35	·159	1·88
7 A	40 „ „ and 36 „ „ „ „ 1	14·1	11·21	9·1	3·82	·162	1·94
19 A	40 „ „ and 36 „ „ in Sul. Am. and Super.		11·23		4·79		1·65

February, 1906.

WM. SOMERVILLE.

APPENDIX TO Dr. SOMERVILLE'S REPORT UPON EXPERIMENTS WITH SEWAGE SLUDGES.

Details relating to the Sewage Sludges used by the Board of Agriculture for Manure Experiments in 1905–6.

Sludge No. 1.

Composite Precipitation Sewage Sludge.—This sludge consists of the precipitate deposited in continuous flow tanks, as the result of adding alumino-ferric, blood, charcoal and clay (together about 50 grains per gallon) to a domestic sewage containing a small proportion of waste liquors from breweries and a gas works.

Having been pressed into cake and then artificially dried at a temperature of about 75° Centigrade, it was stored under cover for some time previous to the taking of the sample.

Sludge No. 2.

Composite Precipitation Sewage Sludge.—This sludge consists of the precipitate deposited in continuous flow tanks, as the result of adding lime (9 grains per gallon) and alumino-ferric (5 grains per gallon) to a domestic sewage. It was made and pressed during the week ending 4th March, 1905, being subsequently dried by placing portions of it in thin layers near a boiler. A further quantity of lime, equivalent to about 120 lbs. per ton of pressed cake, was added previous to the pressing.

Sludge No. 3.

Alumino-ferric Precipitation Sewage Sludge.—This sludge consists of the precipitate deposited in quiescent settling tanks, as the result of the addition of alumino-ferric (9 grains per gallon) to a domestic sewage. It was produced during a dry week ending March, 1905. Having been pressed and partially dried under cover, it was then further dried by placing it in small quantities on either side of a boiler.

Previous to the pressing, a quantity of lime equivalent to 1 cwt. per ton of pressed cake was added to the sludge.

Sludge No. 4.

Composite Precipitation Sewage Sludge.—This sludge consists of the precipitate deposited in a continuous flow tank, as the result of adding calcium phosphate (4 to 5 grains per gallon) in acid solution and subsequently lime (about 1 grain per gallon) to a rather dilute sewage containing a considerable proportion of waste liquors from various manufactories.

It was produced during March, 1905. The wet sludge was first lagooned till spadeable, and subsequently dried artificially by placing it near a boiler for five or six days.

Sludge No. 5.

Septic Tank Sludge.—This sludge consists of the deposit from an open septic tank which had been receiving domestic sewage, mixed with a considerable proportion of waste liquors from various manufactories, for a period of three years. The flow of sewage to the tank during this time was sufficient to fill it once every 24 hours. The tank was cleaned in March, 1905, the sample of sludge used for the experiment being first lagooned till spadeable and then artificially dried by placing it near a boiler.

Sludge No. 6.

Settled Sewage Sludge.—This sludge consists of the deposit settling in the second tank of the general process for the treatment of the domestic sewage and the manufacturing waste from a large city. The sewage was first passed through a detritus tank, then through the tank in question, and subsequently, after having received the precipitant, through several other tanks.

The sample of sludge used for the experiment was first lagooned till spadeable, and finally dried by placing it near a boiler. It was produced in March, 1905.

Sludge No. 7.

Composite Precipitation Sewage Sludge.—This sludge consists of the precipitate deposited in continuous flow tanks, as the result of adding per-sulphate of iron (8 grains per gallon) and lime (4 to 5 grains per gallon) to the domestic sewage and manufacturing waste from a large city. It was produced during the week ending 8th April, 1905. The tank sludge is first pressed, then artificially dried at a temperature of 65° to 70° Centigrade in a special machine, and finally passed through a pan-mill.

COLIN C. FRYE.

CHEMICAL ANALYSIS OF THE SLUDGES USED IN THE PLOT EXPERIMENTS.

	No. 1.	*No. 2.*	*No. 3.*	*No. 4.*	*No. 5.*	*No. 6.*	*No. 7.*
	Native Guano from Kingston.	Dorking Sludge from Lime and Alumino-ferric precipitation.	Chorley Sludge from Alumino-ferric precipitation.	Leeds Sludge prepared by Mr. Alton's process.	Leeds Septic Tank Sludge.	Leeds Settled Sewage Sludge.	Globe Fertilizer from Glasgow.
	Average of 85 samples.	Average of 20 samples.	Average of 26 samples.	Average of 20 samples.	Average of 20 samples.	Average of 20 samples.	Average of 20 samples.
Drawn - -	Mar. 23, 1905	Apr. 5, 1905	Apr. 12, 1905	Apr. 19, 1905	Apr. 11, 1905	Apr. 11, 1905	Apr. 6, 1905
Analysis begun	Mar. 27, 1905	Apr. 6, 1905	Apr. 19, 1905	May 2, 1905	Apr. 17, 1905	Apr. 18, 1905	Apr. 10, 1905
Results given in parts per cent., by weight.							
Moisture (sludge dried at about 110° C.) -	25·67	37·67	12·50	22·06	35·49	17·55	22·51
Matter volatile on heating - - -	37·99	24·81	36·76	47·27	25·02	39·20	33·98
Matter non-volatile -	36·14	37·52	50·74	30·67	39·49	43·25	43·51
	100·0	100·0	100·0	100·0	100·0	100·0	100·0
Grit, etc. (*i.e.*, matter insoluble in hydrochloric acid, after ignition) - -	22·33	6·84	25·30	9·35	11·09	16·51	10·75
[1]Oxide of iron and alumina - -	10·10	3·46	9·37	14·61	10·94	9·22	13·42
[2]Lime - - - -	3·30	23·16	10·32	14·71	9·28	11·93	12·09
[3]Magnesia- - -	–	–	–	–	–	–	–
Potash, soluble in hydrochloric acid -	0·16 (approx.)	0·07	–	–	–	–	–
Potash, soluble in water - - -	0·06	–	–	–	–	–	–
[4]Phosphoric acid (P_2O_5)- - -	1·74	0·66	0·98	2·12	0·66	0·84	1·11
Equivalent to Tribasic phosphate of lime - -	3·80	1·44	2·14	4·63	1·44	1·83	2·42
[5]Nitrogen (total) -	1·93	0·89	1·28	1·04	1·38	1·44	1·50
Nitrogen evolved on boiling the sludge for 2 hours with dilute (0·5%) potash solution - -	0·41	0·03 (May 20th)	0·13 (May 21st)	0·08 (May 24th. Copious mould on the sludge now; this was avoided as much as possible in sampling).	0·38 (May 23rd. Slight grey mould on the surface at this date).	0·21 (May 24th. Slight mould on surface, which was removed).	0·06 (May 22nd. Grey mould on surface. Avoided in sampling).

NOTES : [1]—These oxides will contain the phosphoric acid and possibly a very little of the lime.

[2]—The lime was only precipitated once ; it will contain traces of magnesia.

[3]—A sample of Native Guano, examined in October, 1904, gave 0·42% magnesia.

[4] and [5]—The figures for phosphoric acid and for total nitrogen are in each case the mean of two closely agreeing estimations.

GEORGE McGOWAN.

THE BACTERIOLOGICAL EXAMINATION OF THE SLUDGES.

No. 1.—*Kingston Native Guano.*—As sent to Agricultural Colleges. Average of 85 samples. March 23rd, 1905.

B. coli test.—Negative result with 1 gramme.

Neutral red broth test.—As regards fluorescence, plus 1/1,000 minus 1/10,000 of a gramme. Growth in tube inoculated with 1/10,000 millionth of a gramme, indicating the survival of an enormous number of bacteria.

B. Enteritidis sporogenes test.—Plus 1/1,000 minus 1/10,000 of a gramme.

No. 2.—*Dorking Sludge.*—Dried sludge from lime precipitation after pressing and drying near boiler. Average of 20 samples. No. 2., April 5th, 1905.

B. coli test.—Negative result with 1 gramme.

Neutral red broth test.—As regards fluorescence plus 1/10 minus 1/100 of a gramme. Growth in 1/10,000 of a gramme minus 1/100,000 of a gramme.

B. Enteritidis sporogenes test.—Negative result with 1 gramme.

No. 7.—*Glasgow Sludge.*—Globe fertilizer. Average of 20 samples.

B. coli test.—Negative result with 1 gramme.

Neutral red broth test.—As regards fluorescence plus 1/1,000 minus 1/10,000 of a gramme. Growth in 1/100,000 minus 1/1,000,000 of a gramme.

B. Enteritidis sporogenes test.—Plus 1/100 minus 1/1,000 of a gramme.

No. 5.—*Leeds Septic Sludge.*—Average of 20 samples from No. 4 open septic tank. March cleaning. April 11th, 1905.

B. coli test.—Plus 1/100,000 minus 1/1,000,000 of a gramme. The biological characters of the coli-like microbes characteristic of 1/10,000 and 1/100,000 of a gramme may be given as follows:—

Tests.	1/10,000th gramme.	1/100,000th gramme.
Gelatine shake culture - - - - - - -	+	+
Cane sugar peptone - - - - - - -	Negative.	Bleached and gas.
Neutral red broth - - - - - - -	+	+
Lactose peptone - - - - - - -	Acid and gas.	Acid no gas.
Indol in broth culture - - - - - - -	+	+
Litmus milk - - - - - - - -	Acid and clot.	Acid and clot (slow liquefier).

Neutral red broth test.—As regards fluorescence, plus 1/10,000 minus 1/100,000 of a gramme. Growth in 1/10,000,000 minus 1/100,000,000 of a gramme.

B. Enteritidis sporogenes test.—Plus 1/100,000 of a gramme.

No. 6.—*Leeds Settled Sewage Sludge.*—Average of 20 samples from Tank No. 2. April 11th, 1905.

B. coli test.—Plus 1/1,000,000 minus 1/10,000,000 of a gramme. The biological characters of the coli-like microbe characteristic of 1/100,000 and 1/1,000,000 of a gramme may be given as follows:—

Tests.	1/100,000th gramme.	1/1,000,000th gramme.
Gelatine shake culture - - - - - - -	+	+
Cane sugar peptone- - - - - - -	Acid slight gas.	Bleached no gas.
Neutral red broth - - - - - -	+	+
Lactose peptone - - - - - - -	Acid and gas.	Acid and gas.
Indol in broth culture - - - - - - -	+	+
Litmus milk - - - - - - - -	Acid and clot.	Acid and clot.

Neutral red broth test.—As regards fluorescence, plus 1/10,000,000 minus 1/100,000,000 of a gramme. No growth in 1/100,000,000 of a gramme.

B. enteritidis sporogenes test.—Plus 1/10,000 minus 1/100,000 of a gramme.

No. 3.—*Chorley Precipitated Sludge.*—Average of 26 samples, pressed and boiler dried.

B. coli test.—Plus 1/100,000 minus 1/1,000,000 of a gramme. The biological characters of the coli-like microbes characteristic of 1/10,000 and 1/100,000 of a gramme may be given as follows:—

Tests.	1/10,000th gramme.	1/100,000th gramme.
Gelatine shake culture - - - - - - -	+	+
Cane sugar peptone - - - - - - -	Negative.	Bleached and gas.
Neutral red broth - - - - -	+	+
Lactose peptone - - - - - -	Acid no gas.	Acid slight gas.
Indol in broth cultures - - - - - - -	Negative.	Negative.
Litmus milk - - - - - - - -	Acid no clot.	Acid no clot (slow liquifier).

Neutral red broth test.—As regards fluorescence, plus 1/100,000 minus 1/1,000,000 of a gramme. Growth in 1/1,000,000 minus 1/10,000,000 of a gramme.

B. enteritidis sporogenes test.—Plus 1/10,000 minus 1/100,000 of a gramme.

No. 4.—*Leeds Alton's Sludge.*—Average of 20 samples. Lagooned and boiler dried. April 19th, 1905.

B. coli test.—Plus 1/1,000 minus 1/10,000 of a gramme. The biological characters of the coli-like microbes characteristic of 1/100 of a gramme may be given as follows :—

Tests.	1/100th gramme.	1/1,000th gramme.
Gelatine shake culture - - - - - -	+	No coli-like microbes could be found.
Cane sugar peptone - - - - - -	Negative.	
Neutral red broth - - - - - - -	+	
Lactose peptone - - - - - - -	Acid and gas.	
Indol in broth cultures - - - - - -	+	
Litmus milk - - - - - - - -	Acid and clot.	

Neutral red broth test.—As regards fluorescence, plus 1/10,000 minus 1/100,000 of a gramme. Growth in 1/1,000,000 minus 1/10,000,000 of a gramme.

B. enteritidis sporogenes test.—Plus 1/100,000 minus 1/1,000,000 of a gramme.

Experiments as Regards the Presence of Nitrifying Bacteria.

The results were, in certain directions, somewhat anomalous. But briefly, it may be said that sterile ammoniacal solutions, specially well adapted for the growth of *nitroso-bacteria* (Nitrite producing microbes) were inoculated with the sludges in amounts varying from 1/10 gramme to 1/10,000 millionth of a gramme.

Yet in no case was there any *nitrite* production within a period of five weeks. In some cases, when the cultures were kept for still longer periods, there was some indication of *nitrite* formation. But, on the whole the results were practically negative.

Summary of Results.

The chief results may be tabulated as follows :—

Tabular Statement of Results.

Fluorescence in neutral red broth test, 48 hours at 37°C. Col. 1.	Growth in neutral red broth, 48 hours at 37°C. 2.	B. coli test. 3.	B. Enteritidis sporogenes test. 4.
1. +1/1,000th of a gramme.	+1/10,000th of a gramme.	−1 gramme.	+1/1,000th of a gramme.
2. +1/10th of a gramme.	+1/10,000th of a gramme.	−1 gramme.	−1 gramme.
3. +1/100,000th of a gramme.	+1/1,000.000th of a gramme.	+1/100,000th of a gramme.	+1/10,000th of a gramme.
4. +1/10,000th of a gramme.	+1/1,000,000th of a gramme.	Presumptive + 1/1,000th of a gramme. Confirmatory + 1/100th of a gramme.	+1/100,000th of a gramme.
5. +1/10,000th of a gramme.	+1/10,000,000th of a gramme	+1/100,000th of a gramme.	+1/100,000th of a gramme.
6. +1/10,000,000th of a gramme.	+1/10,000,000th of a gramme	+1/1,000,000th of a gramme.	+1/10,000th of a gramme.
7. +1/1,000th of a gramme.	+1/100,000th of a gramme.	−1 gramme.	+1/100th of a gramme.

Remarks.

It will be noted that all the sludges were rich in microbial life (*see* Column 2). But in sludges 1, 2 and 7, no B. coli were present (Column 3). Sludges 5, 6, 3 contained numerous B. coli (or coli-like microbes). Sludge 4 also contained B. coli (or coli-like microbes) in 1/100 of a gramme.

With the exception of Sample 2, all the sludges yielded a positive result with the B. enteritidis sporogenes test. In some cases a positive result was obtained with fractional amounts of the material.

Taking into account the results shown in Column 1, as well as the results in Columns 2, 3 and 4, the opinion was formed that in the first three sludges the bacilli were killed but not their spores. In the remaining sludges both bacilli (of some kinds) and spores were viable.

Reverting to the experiments as regards nitrifying bacteria, it may be doubted whether any of the sludges could be regarded as effective bacteriologically, in view of the absence seemingly of nitrite-producing microbes Unless the presence of multiple spores of bacteria can be thought of as paving the way towards decomposition of the sludge, and the setting free of substances suitable for plant life, I am of opinion that the physical characters and chemical composition of the sludges will be found to be the determining factors in their agricultural value.

A. C. HOUSTON.

January 31st, 1906.

II.—REPORT ON EXPERIMENTS WITH SEWAGE SLUDGE UPON HAY IN 1907.

Object.—The experiments were carried out with the object of (1) comparing among themselves, as regards manurial value, seven different varieties of sewage sludge, and (2) comparing the action of the several sludges with that of certain artificial manures. By these experiments, it was hoped to obtain some information respecting the value of sewage sludges from the manurial standpoint.

Composition of the Sludges.—The sewage sludges employed in the experiments varied considerably in composition, as will be seen from Table I.

Amounts of Sludge applied.—The standard application was No. 1 sludge, of which sufficient was employed to give the soil 40 lb. of nitrogen per acre. Equal weights of the other sludges were given on other plots, and hence the amount of nitrogen supplied in each case was as stated in Table II.

Artificial Manures used.—The artificial manures employed consisted of Basic Slag and Sulphate of Ammonia. The former was applied on certain plots in quantities which contained either one half as much or the same quantity of phosphoric acid as the standard application of Sludge No. 1, while sulphate of ammonia was similarly applied in quantities containing 20 lb. and 40 lb. of Nitrogen. The amounts both of sludge and artificial manures which were applied to the various plots are given below. (See Table IV.)

General Scheme of Experiments.—The plots were each $\frac{1}{20}$th of an acre, and were so delineated that the experiments can, if necessary, be continued for 1908. The sludge and slag were to be applied in the first half of November, 1906, except in the case of Plot 9, where the sludge was to be applied in the latter half of March, at the same time as the sulphate of ammonia, which was in all cases to be applied in the latter half of March. These methods, with but slight variation, were carried out at all the centres.

Manuring of the Plots (*Quantities per Acre*).—The actual amounts of the sludges and artificials applied to the various plots will be found in Table IV. It may, however, be pointed out here that the first seven plots received equal weights respectively of the seven sludges; plots 8, 9 and 11 received different weights of sludge No. 1; plots 10 and 23 were unmanured; plots 12, 13 and 14 received No. 1 sludge with various artificials; plots 15 to 22 no sludge, but combinations of artificials; while plots 24 and 25 received only lime.

It will be remarked below that at most centres 25 plots were finally included in the experiments, while at Cambridge there were 34 plots.

Centres at which experiments were carried out.—The following is a complete list of the centres at which the experiments were conducted, with the exception of the Woburn Experimental Farm, in which case the field experiments were on a smaller scale and the figures cannot be included in the Table showing the average results. These are presented in a separate report by Dr. Voelcker. The Pot experiments at Woburn are also separately reported.

Centre.	Experiments conducted at
1. The North of Scotland College of Agriculture, Marischal College, Aberdeen	Blaehillie, Udny, Aberdeenshire.
2. West of Scotland College of Agriculture, Blythswood Square, Glasgow	Woodilee Farm, Lenzie.
3. The Armstrong College, Newcastle-on-Tyne - - - - - -	Offerton Hall.
4. The University, Leeds - - - - - - - - -	Manor Farm, Garforth.
5. The University College of North Wales, Bangor - - - - -	College Farm, Madryn.
6. The Agricultural Department, Cambridge University - - - -	Impington.
7. The Rothamsted Experimental Station, Harpenden, Herts - - -	Apple Tree Field, Rothamsted.
8. The South-Eastern Agricultural College, Wye, Kent - - - -	The College Farm.

At Aberdeen (Blaehillie, Udny) the land employed was a poor wet clay worth only a few shillings per acre rent, and the field had been in grass for six or seven years, but was in extremely poor condition. In view of the favourable season the yield was poor. It would seem that the land was uneven in quality, since the two unmanured plots (Nos. 10 and 23) yielded respectively 21 cwt. and 12½ cwt. of hay. The difference in yield between the plots might therefore, so far as the figures go, be accounted for by variations in the soil, but it was remarked by the experimenter that at the last inspection, July 13th, some time before cutting, the effects of the manuring were clearly seen, and the unmanured plots could be easily distinguished. The sludges all produced an extra growth of grass, but before cutting no differences were discernible between one sludge and another. Slag increased the quantity of clover, but heavy dressings did not appear to produce a greater amount than small dressings.

At Glasgow (Woodilee Farm, Lenzie) the soil was a heavy clay in moderate condition; the grass was in its first year, and the crop was a good one. The application of the sludges had a marked effect, as also had the sulphate of ammonia. Basic slag appears to have had little influence.

At Newcastle (Offerton Hall) the soil was clay loam, while the grass had been laid down about thirty years. There was no duplicate "unmanured" plot. The crop was fair. The hay was weighed on August 2nd, and it was found that, while all manures had had effect, the sludges were, on the whole, as productive as the artificials. It will be remarked, however, that although Plot 11 received 50 per cent more sludge than Plot 7, it has yielded less hay, so that in the absence of duplicate plots caution is required in drawing conclusions from these results.

At Leeds (Manor Farm, Garforth) the experiment was made on old meadow herbage on a medium loam. Here all sludges and manures were applied in Spring. The hay crop was fair. There was a wide difference in yield between the two unmanured plots, while the larger amount of sludge on Plot 11 led to no increase of crop over Plot 7, but rather a falling off. Sludges cannot be said to show a consistent effect. Artificials, however, produced slight increases, chiefly when basic slag and sulphate of ammonia were combined.

At Bangor (Madryn) the soil was of a gravelly nature, and the herbage old meadow. The hay crop was good. The experimenter reported that, judging from appearances, the sludges had no effect. The figures confirm this. Again, however, there is considerable difference between the unmanured plots. Sulphate of ammonia had a marked effect on the crop at this centre.

At Rothamsted (Apple Tree Field) the experiment was conducted on old grass on a heavy clay loam. The growth was even and regular on all the plots. The crop was very good. Sludge, basic slag, and lime were applied on November 23rd, 1906, and the sulphate of ammonia, and the sludge on Plot 9, on February 15th, 1907. The crop was cut on July 19th, 1907. A distinct difference between the yields of the unmanured plots must again be remarked, but their average is 39·75 cwt. of hay, compared with an average of 38·33 cwt. for the first seven plots receiving sludges. There is thus no indication of any increase from the use of the sludges. The effect of sulphate of ammonia was again good.

At Wye (College Farm) the soil was a somewhat stiff loam, overlying the lower chalk, and the subsoil contained a fair proportion of chalk. The field has been under permanent pasture for some years; it has been regularly grazed and has not been recently mown for hay. During the growing season there was little difference in the appearance of the plots, but the weighings show considerable irregularity; and although the crops on all the plots were very good, the yields suggest an uneven soil. There was a difference of 4½ cwt. per acre between the unmanured plots. The small application of sludge to Plot 9 in March was followed by the highest yield, but it is improbable that this result could have been due to the manure alone. Again, when on Plot 11, 50% more sludge No. 1 was used than on Plot 7, there was an increase on the former plot of exactly 10 cwt. per acre, and on Plot 7 and on most of the other "sludge" plots there was actually less hay than on the unmanured plots. It is clear, therefore, that no reliance can be placed on the figures obtained at this station.

At Cambridge (Impington) all the plots were duplicated (there were *three* unmanured plots), and it will be worth while to deal with this experiment at some length before presenting the full table of results.

The soil at Impington, where the experiment was conducted, was a medium but sticky loam in low condition, while the grass was a pasture of 15 to 20 years standing. The surface of the field was quite flat and the soil uniform, but the herbage was somewhat uneven. The crop was poor.

The ordinary variations between the yield from duplicate plots would range from 2 to 3 cwt. per acre, but it will be seen from Table III which gives the Cambridge results that in the case of Nos. 4, 13, 26 and 31 the differences between the A and B plots were considerably more. No attention need therefore be given to the figures relating to these four plots.

The manurial requirements of the soil were in this case tested by using farm-yard manure and also common artificial manures. These and the umanured plots provide standards with which to compare the action of the sludges. Plots treated with calcium cyanamide were also introduced.

On Plot 30 a mixed artificial manure produced a very marked increase in the hay crop, and from Plot 33 we find that this increase was chiefly caused by the nitrate of soda present in the mixed manure, for where it was omitted the yield fell almost to the unmanured level. Next to nitrate of soda the phosphatic manure did most good, its omission reducing the crop by 5 cwt. per acre (compare plots 30 and 32). The plots receiving the manure from which potash was omitted were uneven, and no further deduction can be drawn from the result than that the yield obtained on Plot 31B makes it probable that potash was not required by this particular soil.

It will be observed that the yields of Plots 17 and 32 correspond closely, as, theoretically, they should do: sulphate of ammonia is practically equal to nitrate of soda as a source of nitrogen on grass land of this type. Calcium cyanamide on the other hand has been less useful, and it would appear to be distinctly slower in its action than sulphate of ammonia.

The farm-yard manure applied to Plot 26 improved the appearance of the crop, but the figures obtained from the duplicate plots differ so widely that no notice need be taken of them here.

When oilcake has been fed to cattle, the percentage of ammonia present in the manure is much increased, and the effect of this ammoniacal nitrogen on the growing crop was very marked. Plot 27, which received the manures made by cake-fed cattle, closely resembled in appearance the plots dressed with sulphate of ammonia or nitrate of soda, and the figures show that with two exceptions (when 40 lb. of nitrogen in sulphate of ammonia were applied) the crop harvested was the best in the field.

Basic slag, even when applied at the rate of 10 cwt. per acre to Plot 28, produced, as was expected, very little effect, and lime, as is usually the case in the first year after application, produced no effect at all.

No definite effect was produced by any of the sludges, the variations in yield not being greater than might be accounted for by the soil and herbage; nor, in the early season when the quick-acting nitrogenous manures had altered the colour of the plots to which they were applied, could any change in colour be seen on the sludge plots.

Average Results.—The results obtained at each of the eight centres, together with the average results, are given in Table IV. The average results of the four northern and of the four southern experiments have been added for comparison. Bangor has in this case been included among the southern stations. The increase over the average yield of the unmanured plots has been stated for each plot. The table also shows the weight of manures applied and the approximate cost per acre of the artificial manures.

In examining the effects produced by the use of sludge as a manure, it may be observed that little, if any, definite effect upon the first hay crop was to be expected from the phosphates and lime present in the sludges; these constituents of sludge would seldom affect meadow hay until the second year after application. There was, however, one station (Aberdeen) at which the effect of basic slag could be traced on the herbage before the hay was cut, but in this case no similar effect was noticed on the sludge plots. This is an indication that the phosphate found in sludge may be less active than that of basic slag, but further evidence is required on this point.

All the sludges supplied the soil with considerable quantities of nitrogen, and because of this nitrogen they might have been expected to produce the effects of a nitrogenous manure upon the hay crops. In the north, where the wet summer was very favourable to slow-acting nitrogenous manures, they appear to have been useful; and column 16 of Table IV. shows that there was an increase due to sludge of from 5 to 9 cwt. per acre; but in the South of England, where the hay crop is cut much earlier, they produced no results whatever: indeed, the average yield was usually from 1 to 2 cwt. less than on the untreated plots. This negative result has been brought about chiefly by the good crop produced on one of the unmanured plots at Rothamsted and on both plots at Wye. If it is assumed that the improved crops at Aberdeen and Glasgow are due to the nitrogenous compounds present in sludge, then it would appear that these compounds must differ in character. Sludge No. 1 is much the richest in total nitrogen, but better field results have been obtained from the comparatively poor sludges Nos. 2 and 4 than from No. 1. It should be noted, however, that these sludges are rich in lime. It is unlikely that this lime would directly affect the herbage, but it may have aided in the decomposition of the nitrogenous matter and thus have produced the effect of a nitrogenous manure. On this point compare with the results obtained in the Pot experiments at Woburn (see p. 20). This indirect effect of lime on pasture grasses is by no means uncommon.

The figures obtained in this experiment and in the corresponding experiments made last year are not of a satisfactory character, and do not permit of any conclusions as to the relative money values of sludge and artificial manures. The only definite conclusion which may be stated is that, both for root crops and grass, the action of the nitrogenous and phosphatic constituents of sludge is very slow as compared with the effect produced by nitrogen and phosphates supplied in ordinary artificial manures. For such crops as mangels, potatoes and swedes, which have a short period of growth and require quick-acting manures, sewage sludges would not appear to be well adapted, and if they are employed they should be applied in tons rather than in hundredweights per acre.

On the other hand, although these experiments do not supply the evidence, it seems likely that sludge used in proper quantities would form a good dressing for the slow-growing plants of many permanent pastures and meadows. Sludge is unlikely to give satisfaction on the very poor clay-soil pastures which are so much benefited by basic slag, but for old grass land of moderately good quality it should prove useful.

TABLE I.—CHEMICAL ANALYSES OF SLUDGES.

Results given in parts per cent.	No. 1.	No. 2.	No. 3.	No. 3. 2nd. Consignment.	No. 4.	No. 5.	No. 6.	No. 6 2nd. Consignment.	No. 7.
Sample drawn.	Oct. 23, 1906.	Oct. 23, 1906.	Oct. 25, 1906.	Nov. 19, 1906.	Nov. 1, 1906.	Oct. 29, 1906.	Oct. 29, 1906.	Nov. 26, 1906.	Oct. 26, 1906.
Analysis begun.	Oct. 24, 1906.	Oct. 24, 1906.	Oct 29, 1906.	Nov. 29, 1906.	Nov. 2, 1906.	Oct. 30, 1906.	Nov. 5, 1906.	Dec. 1, 1906.	Oct. 30, 1906.
Moisture (Sludge dried at about 110°C.) - - - - - -	10·09	31·24	16·74	14·71	40·61	14·09	3·55	12·09	14·39
Matter volatile on ignition -	49·82	24·91	36·71	34·66	16·79	31·91	38·22	37·13	35·67
Matter non-volatile on ignition -	40·09	43·85	46·55	50·63	42·60	54·00	58·23	50·78	49·94
	100·00	100·00	100·00	100·00	100·00	10·000	100·00	100·00	100·00
Grit, etc. (i.e. matter insoluble in Hydrochloric acid, ignited) -	23·27	7·06	17·41	23·26	5·57	15.56	28·28	16·72	16·28
Oxide of iron and alumina [a] -	12·04	3·87	8·35	8·60	4·43	13·77	12·37	15·66	8·11
Lime [b] - - - - - -	2·34	24·59	12·70	12·87	24·45	11·47	8·40	10·83	13·32
Phosphoric acid ($P_2 O_5$) - -	2·27	0·80	1·17	0·80	1·42	0·86	1·25	1·23	1·03
Equivalent to tribasic phosphate of lime - - - - - -	4·96	1·75	2·55	1·74	3·10	1·38	2·73	2·69	2·25
Nitrogen (total) - - -	2·32	0·94	1·6	1·25	0·55	1·21	1·65	1·62	1·16
Nitrogen evolved on boiling the sludge for two hours with dilute (0.5%) solution of Potash	0·36	0·05	0·28	0·05	0·03	0·22	0·14	0·17	0·05

[a] Obtained by precipitating the acid solution with ammonia ; this will contain the phosphoric acid and possibly a little lime.

[b] Precipitated only once ; will contain, no doubt, traces of magnesia.

Potash was not estimated. One or two earlier samples of sludge were tested for it, but only traces were found.

The figures for phosphoric acid and total nitrogen are in each case the mean of two closely agreeing estimations, excepting that a duplicate estimation of nitrogen in No. 5 was by mistake omitted.

TABLE II.

Sludge.	Nitrogen.	Phosphoric Acid.	Tribasic Phosphate of Lime.	Lime.	Volatile Matter.
	Lb.	Lb.	Lb.	Lb.	Lb.
No. 1 - - - -	40·0	39·13	85·30	40·34	858·90
„ 2 - - - -	16·2	13·79	30·06	423·93	429·45
„ 3 - - - -	27·76	20·17	43·97	218·95	632·88
„ 4 - - - -	9·48	24·48	53·37	421·52	289·46
„ 5 - - - -	20·86	14·83	32·33	197·74	550·13
„ 6 - - - -	28·45	21·55	46·98	144·82	658·91
„ 7 - - - -	20·00	17·76	38·72	229·64	614·95

TABLE III.—THE CAMBRIDGE EXPERIMENTS.

No. of Plot.	Treatment (per acre).	Approximate* cost of Artificial Manuring.	Yields of hay per acre.						Remarks.
			A Plots.		B Plots.		Average.		
		Shillings.	Cwt.	qrs.	Cwt.	qrs.	Cwt.	qrs.	
1	Sludge No. 7, 1724 lb.	—	27	3	24	1	26	0	
2	" No. 6, "	—	27	0	24	3	25	3	
3	" No. 5, "	—	24	3	27	0	25	3	
4	" No. 4, "	—	21	2	14	2	18	0†	† The Duplicate Plots are uneven.
5	" No. 3, "	—	23	1	18	3	21	0	
6	" No. 2, "	—	21	0	19	3	20	1	
7	" No. 1, " = 40 lb. Nitrogen (N.)	—	21	2	22	0	21	3	
8	Sludge No. 1, 862 lb. = 20 lb. N.	—	23	0	22	3	22	3	
9	" No. 1, 862 lb. = 20 lb. N. applied in Spring	—	23	1	20	3	21	3	
10	Unmanured	—	22	3	23	1	23	2‡	‡ Average of three Plots—Nos. 10A, 10B, and 29.
11	Sludge No. 1, 2,586 lb. = 60 lb. N.	—	24	3	25	0	24	3	
12	Sludge No. 1, 1,724 lb. = 40 lb. N. + Sulphate Amm. = 20 lb. N.	11	29	3	33	1	31	2	
13	Sludge No. 1, 1,724 lb. = 40 lb. N. + Basic Slag = 8·88 lb. P_2O_5	1	26	0	17	3	21	3†	
14	Sludge No. 1, 1,724 lb. = 40 lb. N. + Sulph. Amm. = 20 lb. N. + Basic Slag = 8·88 lb. P_2O_5	12	28	2	30	1	29	1	
15	Basic Slag = 8·88 lb. P_2O_5	1	19	3	22	2	21	0	
16	" " = 17·76 lb. P_2O_5	2	24	0	25	2	24	3	
17	Sulphate of Ammonia = 20 lb. N.	11	29	0	28	0	28	2	
18	" " = 40 lb. N.	22	36	2	30	0	33	1	
19	Basic Slag = 17·76 lb. P_2O_5 + Sulph. Amm. = 20 lb. N.	13	28	0	32	3	30	1	
20	Basic Slag = 17·76 lb. P_2O_5 + Sulph. Amm. = 40 lb. N.	24	39	2	40	1	39	3	
21	Basic Slag = 8·88 lb. P_2O_5 + Sulph. Amm. = 40 lb. N.	23	39	3	34	3	37	1	
22	Basic Slag = 8·88 lb. P_2O_5 + Sulph. Amm. = 20 lb. N.	12	32	3	27	2	30	0	
24	Lime = 440 lb. CaO	2	19	2	21	3	20	2	
26	10 tons Dung—made without the use of cake	50	29	2	19	1	24	1†	
27	10 Tons Dung—made with the use of cake	50	35	0	34	1	34	2	
28	10 cwts. Basic Slag	25	23	2	26	3	25	0	
29	Unmanured	—	24	1	—		See No. 10		
30	Super. = 40 lb. P_2O_5 + Sulp. Potash = 20 lb. K_2O. + Nitr. Soda = 20 lb. N.	17	32	0	35	0	33	2	
31	Super. = 40 lb. P_2O_5 + Nitr. Soda = 20 lb. N.	14	27	1	36	2	31	3†	
32	Sulp. Potash = 20 lb. K_2O + Nitr. Soda = 20 lb. N.	16	27	3	29	3	28	3	
33	Super. = 40 lb. P_2O_5 + Sulp. Potash = 20 lb. K_2O.	5	24	3	23	3	24	1	
34	Super. = 40 lb. P_2O_5 + Sulp. Potash = 20 lb. K_2O + Calcium Cyanamide = 20 lb. N.	—	30	1	27	2	29	0	

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* Cost estimated on the following prices: Sulphate of Ammonia £12 10s. per ton; Nitrate of Soda £11 per ton; Sulphate of Potash £10 per ton; Basic Slag £2 10s. per ton; Superphosphate £2 15 per ton; Lime 9s. per ton; and Farm Yard Manure 5s. per ton.

TABLE IV.—SHOWING GENERAL SCHEME OF

1	2		3	4	5	6	7 (d) Aberdeen. Marischal College.		8 Glasgow. West of Scotland Agricultural College.		9 Newcastle-on-Tyne. Armstrong College.		10 (e) Leeds. Department of Agriculture. The University.	
No. of Plot.	Sludge.		Sulphate of Ammonia (a)	Basic Slag (b)	Lime.	Approximate cost of Artificial Manure (c)	Yield per acre.	Increase or decrease of yield per acre over average of unmanured plots.	Yield per acre.	Increase or decrease over average of unmanured plots.	Yield per acre.	Increase or decrease over unmanured plot.	Yield per acre.	Increase or decrease over average of unmanured plots.
	No.	lb.	lb.	lb.	lb.		cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.
1	7	1724	–	–	–	Shillings	27·9	+11·0	47·1	+3·2	41·6	+3·6	37·9	+5·7
2	6	1724	–	–	–		29·3	+12·4	45·5	+1·6	42·5	+4·5	36·8	+4·6
3	5	1724	–	–	–		25·4	+8·5	48·4	+4·5	53·6	+15 6	36·4	+4·2
4	4	1724	–	–	–		21·1	+4·2	57·0	+13·1	37·1	–0·9	35·7	+3·5
5	3	1724	–	–	–		20·9	+4.0	54·3	+10·4	39·7	+1·7	31·8	–0·4
6	2	1724	–	–	–		33·0	+16·1	52·1	+8·2.	34.6	–3·4	31·4	–0·8
7	1	1724	–	–	–		22·7	+5·8	53·2	+9·3	41·6	+3·6	35·7	+3·5
3	1	862		–	–		23·6	+6·7	54·3	+10 4	39·9	+1·9	32·5	+0·3
9	1	862	Applied in Spring.				22·1	+5·2	50·5	+6·6	41·4	+3·4	36·8	+4·6
10	Unmanured		–	–	–		21·2	–	43·0	–	38·0	–	35·7	–
11	1	2586	–	–	–		33·0	+16·1	53·8	+9·9	39·9	+1·9	33·9	+1·7
12	1	1724	100	–	–	11	31·4	+14·5	59·1	+15·2	44·6	+6·6	37·1	+4·9
13	1	1724	–	50	–	1	17·3	+0·4	51·4	+7·5	41·8	+3·8	33·7	+1·5
14	1	1724	100	50	–	12	24·3	+7·4	55·0	+11·1	42·9	+4·9	37·0	+4·8
15	–	–	–	50	–	1	25·0	+8·1	42·5	–1·4	38·3	+0·3	35·0	+2·8
16	–	–	–	100	–	2	18·0	+1·1	47·3	+3·4	38·7	+0·7	36·0	+3·8
17	–	–	100	–	–	11	20·2	+3·3	51·3	+7 4	40·0	+2·0	35·9	+3·7
18	–	–	200	–	–	22	17·5	+0·6	5·7	+21·8	42·7	+4·7	40·7	+8·5
19	–	–	100	100	–	13	32·0	+15·1	64·8	+20·9	40·4	+2·4	40·4	+8·2
20	–	–	200	100	–	24	30·0	+13·1	64·3	+20·4	42·5	+4·5	44·0	+11·8
21	–	–	200	50	–	23	31·4	+14·5	67·1	+23·2	46·8	+8·8	37·5	+5·3
22	–	–	100	50	–	12	44·1	+27·2	58·0	+14·1	46·1	+8·1	38·2	+6·0
23	Unmanured		–	–	–	–	12·7	–	44·8	–	–	–	28·7	–
24	–	–	–	–	*	2	24·3	+7·4	46·1	+2·2	–	–	30·0	–2·2
25	–	–	–	–	*	2	21·4	+4·5	46·6	+2·7	–	–	25·7	–6·5

(a) 100 lb. Sulphate Ammonia=20 lb. N. (b) 100 lb. Basic Slag=17·5 lb. P_2O_5. (c) Cost reckoned as for Cambridge experiments. (d) Owing to an error, sufficient of Sludge No. 1 was not retained to apply to Plot 9 in Spring at Aberdeen, and in place of Sludge No. 1, 62·1 lb. of Sludge No. 3 (second lot), containing the same quantity of Nitrogen as 42·1 lb. of Sludge No. 1, were applied to Plot No. 9 on April 19th. (e) All Sludges applied in Spring. (f) Differences between manured and average of 3 unmanured plots. (g) Differences between the manured plots and the average of 15 unmanured plots. (h) Average of seven

EXPERIMENTS AND RESULTS, WITH AVERAGES.

11.		12.		13.		14.		15		16		17		1a
Bangor. University College of N. Wales.		Cambridge. Department of Agriculture. The University.		Harpenden. Rothamsted Experimental Station.		Wye. South Eastern Agricultural College.		Average.[y]		(h) Average of Columns 7 to 10.		Average of Columns 11 to 14.		
Yield per acre.	Increase or decrease over average of unmanured plots.	Yield per acre.	Increase or decrease over average of unmanured plots. (f)	Yield per acre.	Increase or decrease over average of unmanured plots.	Yield per acre.	Increase or decrease over average of unmanured plots.	Yield per acre.	Increase or decrease over average of unmanured plots.	Yield per acre.	Increase or decrease over average of unmanured plots.	Yield per acre.	Increase or decrease over average of unmanured plots.	No. of plot.
cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	
30·8	−1·2	26·0	+2·6	43·8	+4·0	43·6	−7·4	37·3	+3·0	38·6	+7·0	36·0	− 0·4	1
32·9	+0·9	25·7	+2·3	37·0	− 2·8	44·6	− 6·4	36·8	+2·5	38·5	+6·9	35·0	− 1·4	2
31·4	−0·6	25·7	+2·3	33·8	−6·0	43·4	−7·6	37·3	+3·0	40·9	+9·3	33·6	− 2·8	3
34·3	+2·3	18·0	−5·4	40·0	+0·2	43·0	−8·0	35·8	+1·5	37·7	+6·1	33·8	− 2·6	4
31·5	−0·5	21·0	−2·4	41·1	+1·3	46·1	−4·9	35·8	+1·5	36·7	+ 5·1	34·9	− 1·5	5
33·6	+1·6	20·2	− 3·2	38·0	−1·8	48·0	−3·0	36·4	+2·1	37·8	+6·2	34·9	− 1.5	6
30·9	−1·1	21·7	−1·7	34·5	−5·3	48·2	− 2·8	36·1	+1·8	38·3	+6·7	33·8	− 2·6	7
32·5	+0·5	22·7	−0·7	35·7	−4·1	50·2	−0·8	36·4	+2·1	37·6	+6·0	35·3	− 1·1	8
31·2	− 0·8	21·7	−1·7	36·6	− 3·2	59·6	+8·6	37·5	+ 3·2	37·7	+6·1	37·3	+0·9	9
29·5	—	22·7 23·2	–	36·6	–	48·9	–	34·4	–	34·5	–	34·4	–	10
31·2	−0·8	24·7	+1·3	42·5	+2·7	58·2	+7·2	39·6	+5·3	40·1	+8·5	39·1	+2·7	11
38·0	+6·0	31·5	+8·1	44·5	+4·7	48·9	−2·1	41·9	+7·6	43·0	+11·4	40·7	+4·3	12
29·0	−3·0	21·7	−1·7	41·3	+1·5	54·6	+3·6	36·3	+2·0	36·0	+4·4	36·6	+0·2	13
37·5	+5·5	29·2	+5·8	52·3	+12·5	58·2	+7·2	42·0	+7·7	39·8	+8·2	44·3	+7·9	14
29·0	−3.0	21·0	−2·4	42·0	+2·2	53·4	+2·4	35·8	+1·5	35·2	+3·6	36·3	− 0·1	15
29·4	−2·6	24·7	+1·3	39·5	− 0·3	51·1	+0·1	35·6	+1·3	35·0	+3·4	36·2	− 0·2	16
35·8	+3·8	28·5	+5·1	43·6	+3·8	48·9	−2·1	38·0	+3·7	36·8	+5·2	39·2	+2·8	17
46·8	+14·8	33·2	+9·8	51·6	+11·8	51·8	+0·8	43·7	+9·4	41·6	+10·0	45·8	+9·4	18
37·0	+5·0	30·2	+6·8	47·5	+7·7	44·8	−6·2	42·1	+7·8	44·4	+12·8	39·9	+3·5	19
49·8	+17·8	39·7	+16·3	57·5	+17·7	45·7	−5·3	46·7	+12·4	45·2	+13·6	48·2	+11·8	20
44·5	+12·5	37·2	+13·8	52·9	+13·1	44·8	−6·2	45·3	+11·0	45·7	+14·1	44·8	+8·4	21
45·3	+13·3	30·0	+6·6	45·4	+5·6	51·4	+0·4	44·8	+10·5	46·6	+15·0	43·0	+6·6	22
34·6	–	24·2†	–	42·9	–	53·2	–	34·3	–	28·7‡	–	38·5	–	23
39·1	+7·1	19·5	−3·9	42·5	+2·7	52·8	+1·8	36·3	+2·0	33·5‡	+1·9	38·5	+2·1	24
36·3	+4·3	21·7	−1·7	42·1	+2·3	–	–	32·3	−2·0	31·2‡	−0·4	33·4§	− 3·0	25

unmanured plots only. (*) Plots 24 and 25 received lime at the several centres in the following quantities: Aberdeen, slaked lime=440 lb. CaO per acre; Glasgow 504 lb. lime=431 lb. CaO; Newcastle (not stated); Leeds, 550 lb. lime; Bangor, 448 lb. ground lime; Cambridge, lime=440 lb. CaO; Harpenden, 600 lb. quicklime; and Wye, 1,300 lb. lime. (†) Corresponds with the figure for Plot 29 in Table III. (‡) Average of Columns 7, 8 and 10 only. (§) Average of Columns 11, 12 and 13 only.

February, 1908. T. H. MIDDLETON.

III.—REPORT ON EXPERIMENTS WITH SEWAGE SLUDGE ON GRASS LAND, CONDUCTED AT THE WOBURN EXPERIMENTAL FARM, BEDFORDSHIRE, IN 1907.

The principal experiments conducted at the Woburn Experimental Farm in 1906–7 were those carried out on the wheat crop, the methods adopted being those of pot-culture. Seven different kinds of sewage sludge were sent for trial, and, as there remained some quantity of each sludge after the pot experiments were completed, it was decided to carry out a field experiment with each kind on grass, on a somewhat similar line to that adopted in the field experiments instituted in other parts of the country, by desire of the Royal Commission on Sewage Disposal.

The quantity of material left for disposal being, however, but small, these field experiments had to be on a less extended scale than in the other cases. In place of plots $\frac{1}{20}$th acre as recommended, only $\frac{1}{40}$th acre could be given, and the number of different plots had also to be greatly reduced from those set out in the original scheme. Eventually eleven plots of $\frac{1}{40}$th acre each were marked out in Broad Mead, a field that has long been in grass, but which can only be described as of moderate quality.

The field is on the junction of the lower greensand with the Oxford clay, the soil partaking of the character of both formations.

The original scheme provided for the application of the sludges in question to supply 40 lbs. of nitrogen per acre; this was accordingly adhered to, and seven plots were respectively dressed with each of the seven different sludges at the rate suggested. Other three plots were dressed with ordinary mixtures of artificial manures, and a fourth was left unmanured. Inasmuch as lime entered largely into the composition of some of the sludges, lime was used in the comparative plots with the exception of the unmanured one. The arrangement was as follows:—

Plots 1–7.—Each dressed with one of the respective sludges.
Plot 8.—Superphosphate, 3 cwt.; lime, 5 cwt. per acre.
„ 9.—Untreated.
„ 10.—Superphosphate, 3 cwt.; lime, 5 cwt.; sulphate of ammonia, ¾ cwt. per acre.
„ 11.—Superphosphate, 3 cwt.; lime, 5 cwt.; sulphate of ammonia, 1½ cwt. per acre.

Analyses of the various sludges at the time of their application were made, and gave results as follows:—

	1.	2.	3.	4.	5.	6.	7.
Moisture - - - - - -	8·04	27·28	14·01	38·50	11·38	3·55	14·04
*Organic Matter - - - -	52·12	20·33	34·27	12·87	28·79	36·52	29·84
Oxide of Iron and Alumina -	10·67	2·82	8·26	3·17	13·81	15·70	7·40
†Phosphoric Acid - - - -	2·40	1·06	1·53	1·46	0·98	1·53	0·96
Lime - - - - - -	3·87	26·67	14·76	25·17	12·42	9·48	18·17
Alkalies, magnesia, &c. - -	2·42	14·37	10·44	13·02	18·86	8·26	13·17
Insoluble siliceous matter - -	20·48	7·47	16·73	5·81	13·76	24·96	16·42
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
*Containing Nitrogen - -	2·24	0·91	1·56	0·53	1·49	1·42	1·03
Equal to Ammonia - - -	2·72	1·11	1·89	0·64	1·81	1·72	1·25
†Equal to tribasic phosphate of lime.	5·23	2·31	3·34	3·17	2·14	3·34	2·09

From the above analyses it will be seen that the sludges varied considerably, both in regard to their relative states of dryness and to their chemical composition.

Thus, the moisture ranged from 3½ per cent. (No. 6) to 38½ per cent. (No. 4); the organic matter from 12·8 (No. 4) to 52 per cent. (No. 1); phosphoric acid from just below 1 per cent. (Nos. 5 and 7) to nearly 2½ per cent. (No. 1); lime from 3·8 per cent. (No. 1) to 26·6 per cent. (No. 2); ammonia from ·64 per cent. (No. 4) to 2·7 per cent. (No. 1); lastly the siliceous matter showed considerable variations. These differences depended a good deal upon whether lime had been used or not in the preparation, and to what extent. Omitting the consideration of the value of lime for certain classes of soil, No. 1 sample would be, numerically considered, the most valuable, and No. 4 the poorest of the series. Inasmuch as the quantities applied per acre were regulated by the amounts of nitrogen supplied, so that 40 lbs. nitrogen per acre should be given in each case, the quantities applied per plot varied very considerably. Thus, while Plot 1 received 16 cwt. only per acre, Plot 2 required 39 cwt., and Plot 4, 67 cwt. This brought the actual amounts of organic matter somewhat more equal in each case, but gave great differences in respect of the lime and also of the phosphoric acid. It is hard, indeed, to say exactly on what basis materials so different as these should be compared.

Two of the main points of the inquiry being, as I understand, to ascertain: (1) What the manurial value of these sludges is; and (2) whether, by their nature, they possess any distinctive value not shared in by artificial manures, I added, in my experiment, four other plots of the same size, one of these being untreated, and the other three being dressed with superphosphate or with superphosphate and sulphate of ammonia, in quantities much as they would be applied in practice. But, as the soil was known to be poor in lime, and as lime entered to a material extent into the composition of the majority of the sludges, I added lime to the application of artificial manures, for otherwise any benefit shown might have been solely due to the presence of lime.

In the case of Plot 10 (with ¾ cwt. per acre sulphate of ammonia), the actual weight of nitrogen given was only 16·8 lbs. per acre, and in that of Plot 11 (1½ cwt. per acre sulphate of ammonia), 33·6 lbs. per acre, as against 40 lbs. on the sludge plots. The phosphoric acid applied through the 3 cwt. of superphosphate was 43 lbs. per acre, as against 43 lbs. in sludges No. 1 and No. 2, while the lime given in the 5 cwt. per acre on Plots 8, 10, and 11, came to about 450 lbs. per acre, this not exceeding the lime supplied in the other sludges with the exception of No. 1, which gave 72 lbs. only per acre, it being much poorer in lime than any of the others.

The costs of the artificial dressings were as follows:—

Plot 8.—Superphosphate and lime	about	12s. 6d. per acre.
„ 10.—Superphosphate, lime, and ¾ cwt. sulphate of ammonia	„	21s. 6d. „ „
„ 10.—Superphosphate, lime, and 1½ cwt. sulphate of ammonia	„	30s. 6d. „ „

In order that a proper comparison may be made of the value of the different sludges, one requires to know what these respectively cost to produce, or, at least, what their selling value is. Without this, it is impossible to come to any conclusion of value. To know merely that this or that material is capable of producing a certain increase in crop is not enough; one must know at what cost this increase is procured. Not having before me these particulars (I do not know even if they are available), I could only frame a comparative experiment with artificial manures, at known cost, which would supply approximately the same quantities of the main fertilising ingredients as the sludges would.

The plots were chain-harrowed and rolled before any of the applications were put on. The different sludges were distributed by hand (owing to the smallness of the plots) on February 1st, 1907, the superphosphate and lime being applied at the same time to Plots 8, 10, and 11, but the top-dressings of sulphate of ammonia were not given until much later, viz., April 25th.

All the sludges, with the exception of Nos. 2 and 4 (which were rather "sticky" in nature, and would in practice be rather difficult to sow), were in fair condition and could be easily manipulated. Very little rain fell during the months of February and March, the recorded rainfall at Woburn being only ·99 inch for February, and ·83 inch for March. In April, however, there was much more, and on April 12th, ·44 inches of rain fell, this being the first real washing which the manurial applications received. This fact and the absence of warmth by which the season was marked no doubt militated much against the sludges exercising any decided benefit, and it is, indeed, very probable that the results now recorded cannot fairly be taken as a guide to the real or relative values of the sludges. In all experiments conducted on grass land it is unfair, and often misleading, to take the results of a single year as conclusive, and especially is this the case when an abnormal season like that of 1907 enters into the calculation.

During March and April no differences were discernible on the several plots, and it was not until after the application of the top-dressing of sulphate of ammonia on April 25th that any change could be seen. Early in June the Plots 10 and 11 (to which sulphate of ammonia had been given) began to show a darker colour, and to exhibit a coarser growth of herbage than the rest. This continued throughout until July 11th, when the grass on all the plots was cut and made into hay. Plot 11 (superphosphate, lime, and 1½ cwt. sulphate of ammonia per acre) in particular gave a large crop of coarse grass. The plots, being small, were mown by hand, the hay being ready by July 15th, when the weights were recorded in the field. The results were as follows:—

WEIGHTS OF HAY PER ACRE, JULY 15TH, 1907.

Plot.	Application per acre.	Tons.	Cwt.	Qrs.	Lbs.
1	Sludge No. 1 (= Nitrogen 40 lbs.)	1	19	3	18
2	„ 2	2	3	1	26
3	„ 3	2	3	1	16
4	„ 4	2	4	1	14
5	„ 5	2	3	1	26
6	„ 6	2	2	3	12
7	„ 7	2	7	0	26
8	Superphosphate, 3 cwt.; Lime, 5 cwt.	2	5	1	22
9	No treatment	2	6	3	4
10	Superphosphate, 3 cwt.; Lime, 5 cwt.; Sulphate of Ammonia, ¾ cwt.	2	8	0	24
11	Superphosphate, 3 cwt.; Lime, 5 cwt.; Sulphate of Ammonia, 1½ cwt.	3	3	0	24

The differences between the first six plots are not marked ones, the produce ranging between what is virtually 2 tons per acre (Plot 1), and 2 tons 4 cwt. (Plot 4), differences no greater than one would expect to find in the case of duplicate plots on the same land. Plot 7 gives about 3 cwt. of hay per acre more, but this, when compared with the untreated Plot (9), shows practically no increase distinctly due to the manuring. The same remark applies when Plots 8 and 9 are compared. Seeing that the main difference between Plots 1 and 4 is that the application on the former is richer in nitrogen and poor in lime, while that on Plot 4 is rich in lime, one might be disposed to attribute benefit to the use of lime. Such conclusion, however, is discounted by the fact that Plot 8 (superphosphate and lime) gives but slight increase, and is, in turn, lower in produce than Plot 9 (untreated). The only real conclusion to be come to is that, in the decidedly exceptional season of 1907, the applications had no fair chance of acting, and that any differences shown in the case of Plots 1–9 were not really to be attributed to the particular applications made, but rather to chance. Further, that another season, and probably more than one, would be required before any adequate conclusion could be drawn.

Coming next to Plot 10. Here there would appear to be a slight increase. This, possibly, may be a "chance" one like the rest, but I am inclined to think, especially when it is taken in conjunction with Plot 11, that the more quickly-acting top-dressing of sulphate of ammonia has effected a certain increase in the crop. This is much more marked when we come to the last Plot 11—on which sulphate of ammonia in larger quantity was used, for here there is an undoubted increase, amounting to about 16 cwt. per acre over the unmanured produce. The appearances of the Plots 9 and 10 during the period of growth quite bore this out.

There is, I think, little more to be said than that, for all practical purposes, the sludges did not "tell" during this season, but that they require longer time to show their influence, and that the only clear benefit was to be traced to the more quickly-acting (because more soluble) material, sulphate of ammonia. That even this increase will, in the end, be a beneficial one, is by no means certain, for the mere "flushing" of a grass field to give an extra cut for hay by no means results necessarily in the improvement of the pasture permanently. Here, again, continuation of the experiment for other years is called for.

J. AUGUSTUS VOELCKER.

December 16th, 1907.

IV.—EXPERIMENTS WITH SEWAGE SLUDGES CONDUCTED AT THE POT-CULTURE STATION OF THE WOBURN EXPERIMENTAL FARM IN 1907.

The Royal Agricultural Society of England, on being approached by the Royal Commission on Sewage Disposal to carry out some experiments on behalf of the Commission at the Society's Pot-Culture Station, Woburn, gladly undertook the same, and the following is an account of the work done in 1907.

There were seven different kinds of sewage sludge, in respect of which it was desired to ascertain the general and relative manurial value when used as applications for a wheat crop. The resources of the Woburn Pot-Culture Station lent themselves well to the carrying out simultaneously of the large number of comparative trials necessitated in such an enquiry.

After consultation, it was decided to compare not only the influence of one kind of sludge as against that of another, but also to compare this in each case with that produced by an application of artificial manure supplying practically the same fertilising ingredients and in the same amount.

It was further decided that, after the wheat crop was gathered, the experiments should remain and, possibly, be carried on for a second year.

The seven lots of sludge—marked No. 1 to No. 7—were sent to Woburn and were received there on November 2nd, 1906.

Analyses of them were made just before they were about to be used, and the results (which it may be said, were in close agreement with other analyses made by Dr. McGowan) were as follows :—

——	1	2	3	4	5	6	7
Moisture - - - - - -	8·04	27·28	14·01	38·50	11·38	3·55	14·04
†Organic matter and loss on heating	52·12	20·33	34·27	12·87	28·79	36·52	29·84
Oxide of iron and alumina - -	10·67	2·82	8·26	3·17	13·81	15·70	7·40
*Phosphoric acid - - - -	2·40	1·06	1·53	1·46	0·98	1·53	0·96
Lime - - - - - -	3·87	26·67	14·76	25·17	12·42	9·48	18·17
Magnesia, alkalies, carbonic acid, &c.	2·42	14·37	10·44	13·02	18·86	8·26	13·17
Insoluble siliceous matter - -	20·48	7·47	16·73	5·81	13·76	24·96	16·42
	100·00	100·00	100·00	100·00	100·00	100·00	100·00
*Equal to Tribasic phosphate of lime	5·23	2·31	3·34	3·17	2·14	3·34	2·09
†Containing nitrogen - - -	2·24	0·917	1·56	0·53	1·49	1·42	1·03
Equal to ammonia - - -	2·72	1·113	1·89	0·64	1·81	1·72	1·25
Nitrogen present as salts of ammonia	0·301	0·054	0·161	0·113	0·139	0·081	0·080

Between the seven samples there were considerable differences noticeable. Thus, Nos. 1, 6 and 7 were nearly black in colour, No. 5 was brown, and Nos. 2, 3 and 4 varied from dark-grey to nearly quite white. There were also differences in their condition. No. 4 was distinctly damp and sticky, and its condition was such that a farmer would have some difficulty in distributing it at all evenly. All the others, however, could have been dealt with quite easily ; of them No. 2 had the most moisture (27¼ per cent.), while Nos. 1 and 6 were the driest.

The analyses brought out further marked differences, all showing dependence upon the extent to which lime had been used in the preparation of the sludge. Thus, while No. 1 seemed to have had no lime added in the making, Nos. 6, 5 and 3 had moderate amounts, No. 7, rather more, and Nos. 4 and 2 the most. Accordingly, No. 1 was much the richest both in nitrogen and phosphates, while Nos. 4 and 2 (which contained the most lime) were poor in nitrogen. A further examination of the nitrogen contained showed this to be present to but small extent in the form of available salts of ammonia. There were also considerable variations in the amounts of clay and sandy matters present.

In arranging the details of the experiment, the first consideration was the basis on which to compare the different sludges ; should this be the nitrogen, the organic matter, the phosphoric acid, or the lime they severally contained ? Where such marked variations of composition existed, it was impossible to combine all these different features, and, inasmuch as sewage sludge was believed to be useful mainly because of the nitrogenous organic matter it supplied, it was decided to regulate the applications by the amount of nitrogen which would be contained in them. This quantity was 40 lbs. of nitrogen to the acre, it being also the amount adopted in the other (field) experiments conducted throughout the country at the instance of the Royal Commission.

At the same time it was recognised that, when experimenting with a light sandy soil such as that at Woburn, very poor in lime, it might make a considerable difference whether the sludge applied contained lime in any quantity or not. As this influence, however, could be checked by experiments with artificial equivalents of which lime was a constituent, this was provided for in the arrangement of the details.

The next point was—with what materials could the artificial equivalents of the sewage sludges be best made up ? Inasmuch as the sewage sludges supplied nitrogen mainly in an organic form, it was considered well to use as an equivalent some organic material, such as rape dust, which would yield up its nitrogen slowly on decomposition. The phosphates were supplied by superphosphate, and lime was added when requisite. Buxton ground lime was the kind employed. The question of potash or other alkalies supplied in the sludge did not enter at this stage.

The first two parts of the experiment, accordingly, resolved themselves into:—

(*a*) A comparison of the manurial effect, on the wheat crop, of one kind of sewage sludge as against another, when these were respectively applied in quantities calculated to supply 40 lbs. of nitrogen per acre.

(*b*) A comparison of the effect of each individual sludge with that of an artificial dressing composed of superphosphate, rape dust, and lime, calculated to supply the same amounts of phosphoric acid, nitrogen and lime as did the corresponding sludge. Each of the experiments was to be in triplicate.

While, however, the idea underlying the enquiry was not primarily that of obtaining the money value of the sludges, it was thought well to combine, with the foregoing, another series in which, by the use of ordinary artificial manures such as the farmer could readily purchase, a comparison might be made of the approximate cost at which crop increases would be obtained by the sludges and by artificial manures at known cost. This comparison, however, could only be be a partial one, seeing that no particulars whatever were forthcoming as to the actual cost of producing the different sludges in the form in which they were sent to Woburn, or as to the prices at which they were obtainable by the farmer. In one sense sewage may be regarded as a material, not of profit, but to be got rid of at the lowest possible expenditure; but, even adopting this view, it is necessary to know the comparative cost of each method employed, before the agricultural benefit in increased produce can be set down as a material item. However, the particulars were not at hand, and so the present experiment cannot be regarded as deciding whether it "pays" to employ sewage sludge, but only how far one kind of sewage sludge is superior to another in its agricultural results.

In order to meet, so far as was possible, this further question of approximate cost, a third portion of the experiment was devised in which the sludges were used in equal weights—2 tons per acre—and compared with such ordinary dressings of artificial manures at known cost as a farmer would be likely to employ. The artificial dressings were arranged as follows:—

A.	Cost (say.)	B.	Cost (say.)
2 cwt. Superphosphate	6s.	3 cwt. Superphosphate	9s.
5 cwt. Lime	5s.	10 cwt. Lime	10s.
¾ cwt. Sulphate of Ammonia	9s.	1 cwt. Sulphate of Ammonia	12s.
	20s.		31s.

These quantities were to be used per acre, while 2 tons of sewage sludge per acre might be taken as the approximate amount which a farmer would be likely to apply for a wheat crop. These experiments were also in triplicate.

The three parts of the experiment accordingly were:—

(*a*) A comparison of one sludge with another when each supplied 40 lbs. of nitrogen per acre.

(*b*) A comparison of each sludge with an artificial dressing containing the same amounts of phosphoric acid, nitrogen and lime per acre.

(*c*) A comparison of each sludge, used at the rate of 2 tons per acre, with artificial dressings costing respectively 20s. and 31s. per acre.

In this way it was hoped to answer, among other questions, the following:—

Is there anything in the particular form in which nitrogen and organic matter, for example, are present in sewage sludge, which renders them superior to nitrogen and organic matter supplied in other forms? Is there any mechanical or physical benefit to the soil derivable from the employment of sewage sludge? If there be benefit, is it increased or diminished by the sludge being in a moist or in a dry condition? Is the use of lime in the preparation of the sludge an advantage or the reverse?

With these questions before us, the experiments were begun at the Woburn Pot-Culture Station. They involved the use of sixty-nine pots, each trial being in triplicate, in order to minimise the risk of error. The different materials to be used were analysed and the quantities to be applied were calculated from the analyses. Analyses of the sludges have been given already; the mineral superphosphate gave 28·96 per cent. of "soluble phosphate," the rape dust 5 per cent. of nitrogen (6·07 per cent. ammonia), and the Buxton lime 92·21 per cent. of lime (CaO).

The general method of procedure in carrying out pot-culture experiments at Woburn has been so frequently set out in the *Journal of the Royal Agricultural Society of England* that it is unnecessary to repeat the details. It will be sufficient to say that, in most cases, each pot used in the experiments held 40 lbs. (18·14 kilogrammes) of soil, the remaining ones 32lbs. (14·51 kilogrammes) each. Whenever additions were made to the soil, this was done at the outset, by thoroughly incorporating the added material, be it sludge or artificial manure, with the last 8 lbs. of soil filled into a pot. In the third part of the experiment—where sulphate of ammonia was used—this salt was not given until the spring, and was then top-dressed (April 25th, 1907).

The soil used in the experiments was the ordinary soil of Stackyard Field, and taken from the headlands. An analysis of it gave the following figures (soil dried at 212° F.):—

* Organic matter and loss on heating	3·80
Oxide of iron	4·11
Alumina	2·47
Lime	·38
Magnesia	·32
Potash	·30
Soda	·11
Phosphoric acid	·16
Insoluble siliceous matter	88·35
	100·00

*Containing nitrogen	.14
Available phosphoric acid (in 1 per cent. citric acid)	.023
Available potash (in 1 per cent. citric acid)	.012

As the pots were not throughout of one and the same size, "control" (untreated) pots were arranged for each of the two sizes used. To give an idea of the actual quantity of material used, it may be said that the following were the weights of sludge required per pot, in order to give in each case 40 lbs. (18·14 kilogrammes) of nitrogen per acre.

Sludge No.	1	2	3	4	5	6	7
Grammes per pot	12·3	30·0	17·6	51·9	18·5	19·4	26·7

To give 13·14 kilogrammes nitrogen per acre in the form of rape dust (containing 5 per cent. of nitrogen), it required the employment of 5·5 grammes of rape dust per pot. The amount of superphosphate per pot varied from 1·36 grammes in the case of sludge 5 (equivalent of) to 5·69 grammes in the equivalent of sludge 4; the amount of lime varied from ·461 grammes (equivalent of sludge 1) to 13·04 grammes (equivalent of sludge 4.)

The filling of the pots was completd by December 5th, 1906, and on the following day they were sown with wheat, the variety used being "Square Head's Master." Twelve seeds were sown in each pot, and after the plants came up they were reduced in number to six per pot, these remaining throughout.

The weather at commencement was very unfavourable, and in no case did the shoots appear until January 10th, 1907. The thinning-out to six plants per pot was done on April 11th; a comparison of the rootlets of the plants then removed showed very little difference between one sludge and another, but in each case the artificial equivalents had given the larger and stronger root growth.

About April 22nd the first change in appearance showed itself, the sludge-grown plants being then slightly in advance of the untreated ("control") ones, and the flag presenting a darker colour. The plants of sludges 1 and 4 were the best of the series. On April 25th the top-dressing of sulphate of ammonia was applied in the third series (equivalent of 2 tons of sludge per acre).

By May 24th further differences were noticeable; the equivalents were in most cases rather stronger than the corresponding sludges. Of the sludges, No 2 alone seemed no better than the untreated lot, the others generally showing improvement. Of these sludges 4 and 5 were about the best, then 6 and 7, then 1.

Growth was rapid from now, and in each case the "equivalents" went to the front, and by June 20th, sludge No. 2, which up to then had been behind the others, shot ahead and was the best of the sludges. Sludges 4 and 6 had very irregular plants. As ripening proceeded, the most noticeable point was that the straw was distinctly shorter in the case of the "equivalents" than with the sludges themselves; this held good in every case. The untreated lots ripened off first, then the sludges, and lastly the equivalents. Photographs and measurements of the plants were taken just before harvesting, this latter being done on August 28th, the corn being subsequently threshed out and weighed. The results are set out in the accompanying table.

SEWAGE SLUDGE EXPERIMENTS, WOBURN, 1907, ON WHEAT (POT-CULTURE).

Harvest Results, giving average length of ear and straw, average number of ears and grains, average weight of corn and straw, etc.

Series.	No. of pots.	Treatment.	Average length of		Average number of		Average weight of		Produce as percentage of untreated.	
			ear.	straw.	ears.	grains.	corn.	straw.	corn.	straw.
			inches.	inches.			grms.	grms.	%	%
A*	4	No treatment (control)	2·83	36·60	14·5	545	25·19	42·07	100	100
	3	Sludge No. 1	2·84	37·11	15·3	528	25·26	46·96	100·3	111·6
	3	" " artificial equivalent	2·92	33·90	17	582	30·22	51·94	119·9	123·5
	3	Sludge No. 2	2·82	36·38	17	628	30·96	49·45	122·9	117·6
	3	" " artificial equivalent	2·91	31·98	15·3	581	29·84	48·13	118·5	114·4
	3	Sludge No. 3	2·85	35·72	15·7	579	27·92	46·24	110·8	109·9
	3	" " artificial equivalent	2·82	33·60	17	553	28·59	48·59	113·5	115·5
	3	Sludge No. 4	2·80	35·70	16·6	582	30·45	48·82	120·8	116·1
	3	" " artificial equivalent	2·83	32·72	17·6	573	30·42	52·31	120·8	124·4
	3	Sludge No. 5	2·77	38·40	15·7	555	26·39	48·06	104·8	114·3
	3	" " artificial equivalent	2·85	35·64	18·6	619	30 63	54·29	121·6	129·0
B†	2	No treatment (control)	2·70	37·30	11	393	16·97	32·30	100	100
	3	Sludge No. 6	2.61	37·50	12·7	433	19·20	36·80	113·1	114·0
	3	" " artificial equivalent	2·83	37·50	15	566	25·65	45·27	151·7	140·2
	3	Sludge No. 7	2·80	38·20	10·7	421	18·71	33·25	110·7	103·0
	2	" " artificial equivalent	2·81	36·20	16·5	569	26·25	45·96	154·7	143·3
C	3	No treatment (control)	2·69	34·30	10	356	13·73	25·68	100	100
	2	Sludge No. 1, 2 tons per acre	2·81	35·30	10·5	357	14·08	28·26	102·5	110·1
	3	" No. 2, 2 " "	2·75	34·40	10·3	341	14·80	29·04	107·7	113·1
	3	" No 3, 2 " "	2·74	37·80	11·7	401	16·67	35·01	121·4	136·3
	3	Superphosphate, 2 cwt.; lime, 5 cwt.; sulphate of ammonia, $\frac{3}{4}$ cwt.; per acre—cost 20s.	2·71	35·30	14 7	525	22·90	39·79	166·7	154·9
	3	Superphosphate, 3 cwt.; lime, 10 cwt.; sulphate of ammonia, 1 cwt.; per acre—cost 30s.	2·72	32 20	14·3	514	24·20	38·08	176·2	148·3

* 40 lbs. soil per pot. † 32 lbs. soil per pot.

In compiling the results as set out in the Table, it has to be remembered that each separate experiment was in triplicate; there were, for example, three pots in which sludge No. 1 was used, three in which No. 2, and so throughout. The three of each set were, however, carefully watched and any irregularities noted; similarly at harvest time the produce of each separate pot was weighed and these compared one with another. When any decided inconsistencies were shown, these were rejected and not taken into account in the returns. This is not only an advantage but a necessity in the case of pot-culture work; indeed, on this careful duplication does success in large measure depend, for, otherwise, misleading conclusions may easily be come to. In the present series the need of duplication was shown, inasmuch as in the first lot of untreated pots the corn in two of them was, from some unknown cause, found to be decidedly "smutty," this making a difference of 14 per cent. in the weight. To take these weights as the standard of "no treatment" and to compare all the others with it would clearly have been misleading. Happily, the existence of a second lot of three untreated pots enabled the accidental error to be avoided and, the remaining third pot agreeing well with the three of the second lot, an average of four pots could be taken as a fair standard of comparison. Again, in the untreated pots of Series B., one had to be rejected as not agreeing with the other two; this happened also with sludge No. 1 in Series C. In the case of the artificial equivalent of sludge No. 7, a plant in one pot which bore four stems had the ears completely eaten off by mice, which managed one night to work their way into the enclosure. Happily, the damage done was confined to this one pot and it could thus be eliminated. These points are mentioned as showing the care that has to be observed with pot-culture experiments, in order that results may be properly comparable.

Again, it should be pointed out that in pot-culture work the same conditions must prevail throughout if comparisons are to be made, and it requires very little to upset the balance of such conditions. Thus, though sludges 1 to 5 are strictly comparable with one another, with "no treatment," and with their respective artificial equivalents, inasmuch as the same sized pots and the same weight of soil (40 lbs. per pot) were used, it would not be proper to compare—except as regards "percentage increase"—sludges 6 and 7 with, say, sludges 1 and 2; for in the Series B. smaller-sized pots were used and only 32 lbs. of soil per pot. Hence, sludges 6 and 7 must be taken in connection with their own "control" series. The same remark applies to Series C. A glance at the Table, and the difference of crop results in the respective "control" lots of Series A., B. and C., will exemplify this.

Examination of the Results.

To examine now the results in detail. In Series A. the first general point that will strike one is that, while the treatment has produced but little change in the length of the ear, or in the number of ears, there has been a marked effect upon the length of the straw, the sludge in every instance producing a *longer* straw than its corresponding equivalent in artificial manure.

When, however, the actual *weight* of ripe straw is taken, the balance is almost as uniformly in favour of the artificial equivalent, this equivalent, it will be remembered, supplying the same amount of *nitrogen* per acre. The sludges and their equivalents alike give an increased yield of straw over the "no treatment," this varying from 10 to about 25 per cent. In the corn there is similarly an increase of 10 to 20 per cent. in all cases above the "untreated" produce; the differences, however, between the sludges and their equivalents are not so marked, the equivalents being still rather the better.

Continuing the same considerations to Series B., the same general points are to be noted, but, while the sludges have increased the yield of both corn and straw, the effect of the artificial equivalents has been very much more marked, the increases rising to 40 and 50 per cent.

From these figures it would seem to be generally established that the use of the sludges is capable of producing an increase of 10 to 12 per cent. both in corn and straw over the unmanured produce, as compared with an increase of 16 to 17 per cent. from the use of their artificial equivalents, when nitrogen is taken as the base of comparison. Further, that the tendency of the sludge is to produce a greater length of straw.

To compare, next, the sludges one with another. A critical examination of the table will bring out the fact that the sludge which has undoubtedly produced the poorest result is No. 1, and that sludge No. 6 is but little better. These two stand decidedly behind the remainder. On the other hand, sludges Nos. 2 and 4—and in some respects No. 7—have done the best, while inferior to them are Nos. 3 and 5.

On turning now to see what there may possibly be in the composition of one or other of the sludges to account for the differences produced, one is met by the following prominent facts:—Nos. 1 and 6 (which have done worst) are the driest of the samples, while Nos. 2 and 4 (which have done best) have by far the most moisture. Again, Nos. 1 and 6 are those which contain the least amount of lime, while Nos. 2 and 4 have the most. Thirdly, Nos. 1 and 6 contain the most organic matter and nitrogen, Nos. 2 and 4 have the least.

It is hardly possible to leave this subject, therefore, without coming to the conclusion that these points, viz., the contents of moisture, of lime, of organic matter and of nitrogen have a distinct bearing on the results.

Whether these influences are connected or distinct is a matter for further enquiry, but it would at all events seem to be made clear that lime is not without beneficial action, and that its inclusion in the process of preparing the sludge for use is advisable. Further, that the obtaining of the sludge in a very dry state, though it may have advantages in the matter of transport and keeping, is not directly beneficial from an agricultural point of view. Thirdly, that the value of the sludge does not depend mainly upon its containing a considerable amount of organic matter and nitrogen. These two last points, indeed, may be closely connected, as it is not unreasonable to suppose that in the drying of the sludge so as to get it with low moisture content, the nitrogenous organic matter may be rendered less readily assimilable than is the case when the sludge is left in the more moist condition, Or, again, it may be that the presence of lime in some quantity is needed to decompose the organic matter and make it available for the plant. Or, yet again, it may be suggested that the nitrogenous matters as contained originally in the sludge as prepared (without lime) are possessed of more or less toxic properties and do not form a suitable supply of nitrogen to the plant, but require the "sweetening" action of lime before they can be rendered of use. At all events, it is made clear that it is not on the nitrogenous matter in sludges that their value is to be based, so far at least as their effect on a first crop of corn is concerned. Whether the action may not be a delayed one, is what another year's experimental work may determine, and this has been arranged for.

Lastly, in regard to cost, it will be seen from Series C. that the result of using the sludges in such quantity as a farmer might be expected to use them is in no way equal, when a wheat crop is taken, to that produced by a dressing of artificial manure costing 30s. per acre, or even one costing 20s. per acre. This would seem to point to the conclusion that it would not "pay" the wheat grower to give anything like 10s. a ton for even the best of such sludges as were the subject of this inquiry.

CONCLUSIONS.

The following general conclusion may be drawn from the first year's work, so far as the wheat crop is concerned :—

(1) That the different sewage sludges, when used in quantity to supply 40 lbs. of nitrogen per acre, are capable of increasing the yield of both corn and straw by 10 to 12 per cent. above the unmanured produce.

(2) That "artificial equivalents" of the different sewage sludges applied as above will give rather better results, the increase in corn and straw being 16 to 17 per cent. over the unmanured produce.

(3) That the tendency of the use of sewage sludges is to produce a greater length of straw.

(4) That, as between different sewage sludges, those have done best which contain the most moisture and the most lime.

(5) That the value of sewage sludge does not turn mainly upon the amount of nitrogenous organic matters contained, but that these may, indeed, be in a form incapable of ready assimilation and requiring lime for their decomposition.

(6) That, from a practical point of view, none of the sewage sludges used would be worth 10s. a ton on the farm, for wheat-growing purposes

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